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WIND TUNNEL TESTS OF A FULL-SCALE ROTOR AT HIGH SPEEDS

By

C. L. Livingston

July 1965

U. S. ARMY AVIATION MATERIEL LABORATORIES

FORT EUSTIS, VIRGINIA

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BELL HELICOPTER COMPANY

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WIND TUNNEL TESTS OF A FULL-SCALE ROTOR AT HIGH SPEEDS

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SUMMARY

A wind tunnel program was conducted to determine the effects of compressibility and advance ratio on full-scale rotor performance. Based on methods and input data of References 5 and 10, the computed rotor power required with increasing tip speed and advance ratio did not agree with high advance ratio test data. An attempt to improve the correlation was made by synthesizing new airfoil lift and drag characteristics with Mach number and angle of attack. Mach number and lift effects were somewhat improved; advance ratio effects were unchanged.

The tests were made in the NASA-Ames full-scale wind tunnel. The three-bladed, 46-foot-diameter test rotor was gimbal mounted to the mast. Prior to these tests, a rotor of the same design was flown on the Bell-U. S. Army Aviation Materiel Laboratories* (USAAVLABS) High Performance Helicopter (HPH) and these flight test results are reported in Reference 2.

The HPH three-bladed, gimbaled rotor design was adapted to the NASA-Ames tripod test stand, and components were fabricated. Prior to delivery, the rotor was whirl tested on a bailed UH-1D to check alignment, balance, and track. During the test program, a swash plate actuator failed, and the rotor was destroyed.

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* Formerly, U. S. Army Transportation Research Command.

FOREWORD

This report summarizes the results of a wind tunnel program conducted to define the effects of compressibility and advance ratio on full-scale rotor performance. The program was conducted by Bell Helicopter Company under contract DA 44-177-AMC-42(T) (Reference 1) with the U. S. Army Aviation Materiel Laboratories in cooperation with the NASA-Ames Research Center. The three-bladed, gimbaled rotor system used for testing was the same as the rotor system flown on the high performance helicopter reported in Reference 2. Design of new components required to adapt the rotor system to the NASA-Ames 40-by-80-foot wind tunnel test stand began on 28 June 1963. Components were shipped to NASA-Ames on 1 April 1964, and testing started on 11 August 1964. The rotor system was destroyed in the tunnel on 25 August 1964 and testing was terminated. The incident report (Reference 3) was submitted during September 1964. To improve the correlation between the calculated and measured data, additional analytical work was done, the results of which are included in this report. The analytical work was sponsored by the Bell Helicopter Company Internal Research and Development program.

Acknowledgement is made to the personnel who materially assisted in the conduct of the tests: Messrs. J. L. McCloud, III, and J. C. Biggers of NASA-Ames Research Center; and Messrs. K. Hampton and J. R. Crigler, Jr., of the U. S. Army Aviation Materiel Laboratories. Bell Helicopter Company engineering personnel associated with these tests were Messrs. R. N. Baggett, B. L. Blankenship, E. L. Brown, W. L. Cresap, J. M. Drees, D. L. Kidd, W. A. Kuipers, and R. R. Lynn.

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SYMBOLS

Nondimensional parameters are indicated by an "nd" in the Units Column.

Symbol	Meaning	Definition	Units
a	Resultant rotor force vector orientation	$\tan^{-1}(C_{X_R}/C_{L_R})$	rad.
A	Rotor disk area	πR^2	ft^2
c	Rotor blade chord	distance from leading edge to trailing edge	ft
C_d	Local blade drag coefficient	conventional	nd
C_{d_r}	Local blade drag coefficient for flow in the radial direction	conventional	nd
C_{L_R}	Rotor vertical force coefficient	$L/\rho A(\Omega R)^2$	nd
C_P	Rotor power coefficient	$HP \cdot 550/\rho A(\Omega R)^3$	nd
C_{P_o}	Rotor profile power coefficient	on Page 3	nd
C_{X_R}	Rotor horizontal force coefficient	$X/\rho A(\Omega R)^2$	nd
HP	Rotor horsepower based on balance frame yawing and rolling moments	conventional	hp
L	Rotor vertical force (positive up)	perpendicular to V, opposite to gravity	lbs
M	Mach number	conventional	nd
n	Number of rotor blades	3 for test rotor	nd
R	Rotor radius	distance from centerline to blade tip	ft

SYMBOLS (Cont'd)

Symbol	Meaning	Definition	Units
U	Total nondimensional velocity at a blade element	Velocity/ΩR	nd
U_p	Nondimensional velocity parallel to the mast at a blade element	Velocity/ΩR	nd
U_r	Nondimensional velocity in the radial direction and parallel to the blade at a blade element	Velocity/ΩR	nd
U_t	Nondimensional velocity perpendicular to U_p and U_r	Velocity/ΩR	nd
$U_{\Delta X}$	Nondimensional change in velocity in the X direction due to drag force in the radial direction	Velocity/ΩR	nd
V	Rotor forward speed	-	$\frac{ft}{sec}$
x	Blade radial station	fraction of R	nd
X	Rotor horizontal force (positive aft)	parallel to V	lbs
α	Angle between mast and perpendicular to free stream	positive for mast tilted aft	rad
β	Blade flapping angle	conventional, relative to mast axis	rad
Δ	A small change in a variable	-	
θ_o	Rotor collective pitch	angle at the centerline of rotation between the blade zero lift line and the plane perpendicular to the mast	deg

SYMBOLS (Cont'd)

Symbol	Meaning	Definition	Units
λ	Inflow ratio	conventional, relative to mast axis	nd
μ	Advance ratio	conventional, relative to mast axis	nd
μ'	Speed ratio	$V/\Omega R$	nd
π	Constant	3.14159...	nd
ρ	Air density	-	$\frac{slugs}{ft^3}$
σ	Rotor solidity	$nc/\pi R$	nd
ϕ	Local inflow angle at a blade element	$\tan^{-1}(U_p/U_t)$	deg
ψ	Rotor azimuth station	measured counter-clockwise from downwind position	deg
Ω	Rotor rotational speed	-	rad/sec

INTRODUCTION

Early efforts to predict rotorcraft performance (References 6 and 7) gave results that correlated with measured data within about 5 percent at speeds below 120 knots. As tip speeds and forward speeds increased, the measured power increased more rapidly than predicted with the "linear theory" equations. Digital computer techniques were developed (Reference 8) that eliminated most small angle assumptions and included reverse flow and compressibility effects. Correlation was still not sufficiently accurate to enable extrapolation to high speeds with confidence.

The main difficulty in correlating flight test data is the determination of the actual rotor loading. Application of model data obtained at high tip speeds is questionable because of undefined scale effects. The validity of theoretical analyses is questionable due to uncertain two-dimensional airfoil characteristics and the effects of unsteady, three-dimensional flow. Reliable full-scale rotor performance data could be obtained only by controlling the test conditions. Such control was available only in a full-scale wind tunnel.

In early 1963, Bell Helicopter Company proposed to the Department of the Army that a rotor research program be conducted in the NASA-Ames full-scale wind tunnel. A contract was awarded in June 1963, to manufacture and test the three-bladed gimbaled rotor as proposed.

The objectives of this research program were to:

1. Provide rotor performance data obtained under controlled full-scale test conditions.

2. Define the lift capability of the test rotor from very low to high disc loadings at high tip speeds and advance ratios.

3. Determine the propulsive force capability of the test rotor at high advance ratios.

DESCRIPTION OF ROTOR SYSTEM

Table I summarizes the physical parameters of the test rotor and wind tunnel test stand. Figure 1 shows the rotor installed in the wind tunnel. A rotor of the same design as the test rotor was flown on the high performance helicopter in both rigid and gimbaled configurations. The results of these flight tests are given in Reference 2.

Three electrically-controlled, hydraulic actuators positioned the swash plate relative to the mast. These actuators were not installed when the photograph in Figure 1 was taken. The actuators replace the fixed links that position the non-rotating portion of the swash plate. Collective, longitudinal and lateral control were input to the control panel. The input signals were mixed electrically and the actuators positioned accordingly. The control system is described in detail in Reference 9.

Strain gages were used to monitor loads of critical components and to provide blade load distribution data. Table II summarizes the instrumentation of the rotor system. Infinite life loads were never exceeded. During the tests, the following loads were monitored on the components:

- Mast bending
- Yoke beam and chord bending
- Pitch link axial load
- Drag brace axial load
- Hub flapping position

Calibration and Repeatability

All strain gage calibration was done prior to shipment. The gage readings for a given load were repeatable within 2 to 5 percent. No hysteresis was evident. Calibration of the position indicators was accomplished after installation in the wind tunnel. Collective, longitudinal, and lateral cyclic pitch positions were repeatable within 0.2 degree. Collective-cyclic coupling, introduced by the electronic control circuitry, was less than 0.3 degree throughout the collective range.

SUMMARY OF ANALYSES

AERODYNAMIC ANALYSIS

Data Basis

All rotor performance calculations were made using the equations and procedures described in Reference 10. The basic equations used are the same as those of Reference 8, except the small angle assumptions have been removed. Uniform inflow was used for all calculations and assumed to be equal to the momentum theory value. Triangular inflow distribution was used at a few points but did not alter the computed performance significantly. Initially, the airfoil characteristics of Reference 5 were used (Figures 2 and 3). Better correlation was obtained with the airfoil characteristics synthesized for this report and given in Table III and Figures 5 and 6. Stalled characteristics were not changed significantly and are given in Figure 4.

Test rotor performance was computed at the test conditions proposed in Reference 4, and the results of these preliminary calculations are presented therein. These results are not given in this report, as the test rotor radius was a foot longer than the proposed rotor radius and since Mach number effects cannot be nondimensionalized accurately. Two characteristics of rotor performance were examined in the reduced measured data. Calculated and measured rotor power and rotor derivatives were compared.

The basis of the power comparison is the profile power which is defined to be the measured power less the ideal values of induced and propulsive power. The resulting nondimensional expression for profile power is:

$$\left.\frac{C_{P_o}}{\sigma}\right|_1 = \frac{C_P}{\sigma} - \frac{\sigma}{2\mu'} (C_{L_R})^2 - \mu' (C_{X_R})$$

Without resolving the drag vector by cos ϕ, the profile power should be

$$\left.\frac{C_{P_o}}{\sigma}\right|_2 = \frac{1}{2} \cdot \frac{1}{2\pi} \int_0^{2\pi} \int_0^{1} C_d \, U^3 \, dx \, d\psi$$

The above two values of C_{p_o}/σ were computed for each datum point. For 95 percent of the points, the two values were equal within 1 percent. This indicates that subtracting the ideal values of induced and propulsive power from total power is a valid method of obtaining rotor profile power.

The rotor derivatives were calculated by holding all parameters constant except the variables of interest and power. The latter was adjusted as necessary to maintain rotor speed.

Analysis Performed

The major analytical effort was concerned with obtaining better correlation between the measured and computed data. The differences between the measured and computed rotor performance are discussed in detail in the Test Results section of this report. To obtain better correlation, the airfoil lift and drag relationships to angle of attack and Mach number were changed. For this study, data points were selected at representative values of low (.03) and high (.09) rotor lift coefficients for each advance ratio and tip Mach number tested.

The technique developed to modify the data tables depends upon the validity of two assumptions:

1. That the primary profile power loss occurs near the blade tip, and

2. That the blade section drag coefficient is determined by blade section angle of attack and Mach number only.

The validity of the latter assumption is assumed in all published rotor performance analyses that include stall, compressibility, and reverse flow effects. Some work is known to have been done that also includes Reynolds number, but the accuracy of these data is questionable.

The first assumption was justified during the study by printing the profile power parameter, $C_d U^3$, at every blade radial and azimuthal station computed. The sum of the $C_d U^3$ values inboard of the .85 radius never exceeded the sum of the values from .85 to 1.0 for the rotor operating states tested. Hence, the value of drag coefficient and velocity of the tip station was assumed representative of the profile power required at each azimuth station. At advance ratios over about .5, the profile power required in the reverse velocity region becomes significant, and the technique used to modify the airfoil data tables may have to be modified.

This technique involves the following steps:

1. Using Cartesian graph paper, with Mach number on the ordinate and angle of attack on the abscissa, the calculated M-α contour of the blade tip is plotted at each azimuth. See Figure 7.

2. Step 1 is done at low and high rotor lift coefficients, different tip Mach numbers, at the advance ratios of interest until all contours are made.

3. The calculated data are compared to the measured data for the correct trend of:

   a. Profile power increase with rotor lift coefficient.
   b. Profile power increase with tip Mach number.
   c. Profile power increase with advance ratio.

4. By the second assumption mentioned above, each combination of Mach number and angle of attack has a unique drag coefficient associated with it. The problem then becomes one of determining the correct drag coefficient for each M-α. By overlaying the contours, it can be seen that the drag value in one M-α region can be changed without significantly altering the profile power of a datum point whose contour does not enter the region where C_d is changed.

5. Using these contours, and the conventional C_d versus angle of attack plot of the data tables (Figure 6), it may be seen where the drag coefficients can be changed to improve correlation.

This technique involves successive approximations and exercising considerable judgement. The profile power increase with rotor lift coefficient and tip Mach number have been fairly accurately determined using this method. The profile power increase with advance ratio could not be significantly altered because the contours covered the same M-α region. Therefore, if the drag coefficient was changed in a M-α region in order to improve advance ratio correlation, the correlation with rotor lift would be worse. This paradox indicates that additional analytical work is necessary to re-examine the mathematical representation of the rotor and the assumption of a unique C_d-M-α relationship.

The determination of the C_l-M-α relationship was more straightforward. The lift curve slope with Mach number was greatly reduced for Mach numbers from .2 to .7. Maximum lift coefficients were not involved, since none of the data obtained involved a significant amount of stall and none of the computed angles of attack were beyond the stall angle for the associated Mach number. Lift coefficients beyond the stall angle of attack were not determined by this analysis.

Because of the difficulty of correlating the profile power increase with advance ratio, the effects of including radial flow were investigated. A rapid analysis of this effect was made by calculating the profile power parameter:

$$\left.\frac{C_{P_o}}{\sigma}\right|_2 = \frac{1}{2} \cdot \frac{1}{2\pi} \int_0^{2\pi} \int_0^1 C_d U^3 \, dx \, d\psi \qquad (1)$$

where U is the nondimensional velocity at a blade element.

Conventional analyses vectorially sum the perpendicular and tangential velocity components to obtain the total velocity, U. If radial flow is included, then the radial velocity component is added vectorially to the perpendicular and tangential component to obtain the total velocity, U. The expressions for these components are:

$$U_p = \lambda - \mu \beta \cos \psi - \frac{x}{\Omega} \frac{d\beta}{dt} \qquad (2)$$

$$U_t = x + \mu \sin \psi \qquad (3)$$

$$U_r = \lambda \beta + \mu \cos \psi \qquad (4)$$

For a quick analysis of the effect of radial flow on power, λ, β, and $d\beta/dt$ were set to zero and the integral was evaluated numerically for advance ratios from .1 to 1. A curve was fitted through the data points, and the following expressions for profile power resulted. The drag coefficient, C_d, was assumed not to vary with x or ψ.

$$\frac{C_{P_o}}{\sigma}_{\text{conv.}} = \frac{C_d}{8} (1 + 2.71 \mu^2 + .44 \mu^3) \qquad (5)$$

$$\left.\frac{C_{P_o}}{\sigma}\right|_{\substack{\text{incl.}\\ \text{rad. flow}}} = \frac{C_d}{8}\left(1 + 3.8\,\mu^2 + 1.8\,\mu^3\right) \tag{6}$$

The appearance of a much larger μ^3 term and an increased μ^2 term indicated that the radial flow correction may be what was needed in the rotor performance program. The basic equations were derived, including the radial velocity component and a local "sweep" angle. The airfoil characteristics were not considered to be altered by the sweep angle.

The expected increase of profile power was not calculated by the computer program. The reason was that all angles of attack were reduced, which had more effect on lowering the local drag coefficients than the increased velocity did on raising them. The net result was that, for a given datum point, the rotor produced the same thrust and X-force as before considering radial flow, but the angles of attack were everywhere reduced. On the retreating blade, this had great effect since the angles of attack were high and a relatively small angle-of-attack change resulted in a large change in drag coefficient.

Another method of including radial flow would be to consider the X-force component of the skin friction drag in the radial direction. If this is calculated as an addition to the X-force and multiplied by the advance ratio, the profile power will increase since the angle-of-attack distribution will not change significantly. Substituting

$$U_{\Delta X} = \mu \sin^2 \psi \tag{7}$$

into

$$\Delta \frac{C_{P_o}}{\sigma} = \mu \cdot \Delta \frac{C_{\Delta X}}{\sigma}$$

$$= \mu \cdot \frac{C_{d_r}}{2} \frac{1}{2\pi} \int_0^{2\pi} \int_0^1 U^2_{\Delta X} \; dx \; d\psi \tag{8}$$

and evaluating, yields,

$$\Delta \frac{C_{P_o}}{\sigma} = \frac{C_{d_r}}{8} (1.5 \mu^3) \tag{9}$$

If C_{d_r} is assumed to equal C_d, then the profile power will increase by $1.5 \mu^3$, which is approximately the difference between the μ^3 terms in equations 5 and 6.

It would then appear that radial flow corrections to the mathematical representation of the rotor are desirable. However, the corrections considered are not adequate to explain the rapid increase in measured profile power with advance ratio. Additional work with the drag data tables may improve the profile power increase with advance ratio. The correlation of measured and calculated longitudinal cyclic control positions is improved with radial flow.

DYNAMIC ANALYSIS

The complete dynamic analyses are given in References 11 and 12. Reference 11 investigated the shaft critical speeds for the rotor on the upper and lower splines. During the tests, the rotor was mounted on the lower splines.

Inertia and stiffness calculations were made for the Ames drive train, from the floor transmission to the support transmission, and the test mast and rotor. The following modes of motion were considered:

1. Mast bending: pin-pin at the mast-drive train coupling and the upper bearing, support transmission. The transmission was assumed rigidly supported.

2. Mast-drive train bending; pin-pin at the upper bearing, tunnel floor drive transmission, and the mast drive train coupling. The support transmission was assumed pinned.

For the first case, the shaft critical speed was calculated to occur at 456 rpm. For the second case, the shaft critical speed was calculated to occur at 528 rpm. Both speeds are well above operating speed, and no resonant condition exists for either one- or three-per-rev forcing frequency.

The coupled natural frequencies of the test rotor were determined in Reference 12. The analysis described in Reference

17 was used. The effects of adding 25 pounds of weight at the mid-span and tip were evaluated. The results of the study indicated that 25 pounds of mid-span weight should be used on the 46-foot rotor to avoid three-per-rev resonance in the second cyclic mode.

The variation of blade coupled natural frequency with collective pitch and several rpm is shown in Figures 8 and 9. The coupled frequencies are separated into collective and cyclic modes of motion that are defined as follows:

> A collective mode is a combination of beamwise symmetric and chordwise antisymmetric displacements. For a three-bladed rotor, collective modes are sensitive to excitation at multiples of three times rotor speed.

> A cyclic mode is a combination of beamwise antisymmetric and chordwise symmetric displacements. For a three-bladed rotor, cyclic modes are sensitive to excitation at multiples of the rotor speed other than three-per-rev.

Rotor loads were computed for the tunnel operating conditions using techniques of Reference 17. The load values are presented in Reference 18.

WHIRL TESTS

The 46-foot- and 36-foot-diameter test rotors were installed on a bailed UH-1D(48) so that balance, track, and general rotor behavior could be checked prior to shipment. The 36-foot rotor was whirl tested but was not tested in the wind tunnel. The 46-foot rotor exhibited a vertical one-per-rev resonance through a narrow collective pitch range. Several fixes were tried: an adjustable lift link, tying the skid gear together, loose and tight tie-down cable, pylon mounts locked out. None of the fixes significantly reduced the magnitude of the resonance. Since the collective pitch range that excited the resonance was very narrow, it was decided to fly the ship.

There was no problem getting through the critical collective pitch range. One-per-rev vibration from hover to 50 knots was acceptable to the pilot. The one-per-rev resonance encountered during tie-down was not evident in flight, even during rapid decelerations from 50 knots. From the pilot report, "there (was) no obvious difference in this rotor (and) the previous gimbaled, three-bladed rotor." The "previous" rotor refers to the three-bladed rotor tested and reported in Reference 2.

The 36-foot-diameter rotor was balanced and tracked using normal procedures. No resonance problems occurred during tie-down tests. Lack of roll control in hovering restricted forward flight testing. The cause for this was considered to be beyond the scope of these initial tests and was not determined. The rotor system was considered ready for shipment.

TEST PROCEDURE

The "sweep" procedure described in Reference 14 was used for these tests. Charts were prepared prior to testing so that parameters could be changed rapidly. Because of interference problems, the mast angle could not be changed during a run. The test conditions were set up as follows:

Set mast at angle for desired horizontal force range

Set rotor tip speed to desired tip Mach number based on tunnel temperature

Set tunnel speed to desired advance ratio based on barometric pressure

Adjust fore-and-aft cyclic pitch for approximately zero flapping at 6000 pounds lift

Adjust collective pitch to desired vertical force

After the first datum point was obtained, cyclic pitch was fixed and collective pitch was raised and lowered to obtain data for C_{L_R} values from about .01 to .10. Cyclic pitch was then varied slightly from the initial trim point at a C_{L_R} of .05 to obtain partial derivative data with respect to angle of attack. After data were obtained at the set tip Mach number and advance ratio, the rotor speed and tunnel speed were changed to set the next Mach number and advance ratio.

TEST RESULTS

AERODYNAMIC

The reduced wind tunnel data, provided by NASA-Ames Research Center, are given in Table IV, and the nomenclature used to identify the data is given in the back of the table. Table V gives the control positions for each datum point.

Figures 10 to 12 show a comparison between measured data and that computed by the charts of Reference 5. Also shown are the data computed by the contractor's digital computer program (Reference 10), using the airfoil characteristics of Reference 5. The charts of Reference 5 indicate that profile power coefficient slopes with rotor lift coefficient are approximately correct. However, when the airfoil data of Reference 5 are used in the program of Reference 10, the calculated slopes decrease considerably.

The values of calculated profile power at any rotor lift coefficient are lower than measured. More important than this is the fact that the difference is increasing with increasing advance ratio. Figure 13 illustrates this effect by cross plotting the data of Figures 10 to 12 at a rotor lift coefficient of .05. If this difference between measured and computed data continues to higher advance ratios, the calculated profile power becomes significantly lower than would actually be required.

Figures 14 to 16 show the measured and computed rotor derivatives at the advance ratios and tip Mach numbers tested. The airfoil data of Reference 5 were used in the program of Reference 10 to obtain the calculated data. Derivatives were obtained at a rotor lift coefficient of .05. The computed rotor lift curve slope with angle of attack and collective pitch is approximately 20 percent too high. It should be noted that the mast axis system is used instead of the control axis system. The resulting values of $da'/d\alpha$ are then about unity instead of zero.

The lack of correlation apparent in Figures 10 to 16 prompted additional study of the airfoil lift and drag characteristics used to compute rotor performance. It was immediately noticed that the section lift curve slopes should be reduced, the drag coefficients associated with high Mach numbers should be reduced, and the drag coefficients associated with high angles of attack should be increased. The procedure used to synthesize new airfoil characteristics are described in the Summary of Analysis section of this report. The final airfoil characteristics synthesized are given in Table III and illustrated in Figures 5 and 6. The resulting rotor performance is shown in Figures 17 to 19.

Compressibility

The data obtained have indicated that the previously predicted power increase due to compressibility was overestimated. Figures 10 to 12 show that the measured profile power increase with tip speed at low rotor lift coefficients is within the accuracy of the data. As advance ratio and rotor lift coefficient increase, the effects of tip speed become more noticeable but are still small compared to the previously predicted performance. It should be noticed that all the measured profile powers do not increase significantly as the rotational tip Mach number increases from .49 to .58.

Rotor Lift

Figures 10 to 12 also show the increase in profile power with rotor lift. Using the airfoil characteristics of Reference 5 in the computer program of Reference 10, the calculated slopes are considerably lower than measured. The charts of Reference 5 predict the correct lift slope variation although the overall correlation is not good. Further study of performance techniques in this area is needed.

The slope of the C_{P_O}/σ versus C_{L_R} curve increases with increasing advance ratio as predicted by linear theory (References 6, 15, and 16). The rotor lift coefficient where stall effects tend to increase the profile power cannot be calculated by linear theory. At an advance ratio of .2, this profile power increase occurs at a C_{L_R} of about .10, and at .3 advance ratio the profile power increases at a C_{L_R} of about .7. At an advance ratio of .4, there is no clear value of C_{L_R} where the profile power begins to increase sharply. The overall slope, however, is much higher than at .2 or .3 advance ratio.

Advance Ratio

The increase in profile power with advance ratio is apparent in Figures 10 to 12. Figure 13 shows a cross plot of the measured and calculated data at a C_{L_R} of .05. The slope of the measured profile power versus advance ratio is higher than calculated. Neither the charts of Reference 5 nor the computer program of Reference 10 compute profile power increase with advance ratio near those measured. Incorporating radial flow into the analysis did not improve correlation.

It is believed the measured data is too consistent to be as much in error as indicated. Further study of this effect is warranted, especially since high speed rotorcraft will probably operate at advance ratios from .4 to .7 or higher.

DYNAMIC AND LOADS

The oscillograph records were closely examined, and the most important load channels were reduced at the Ames wind tunnel immediately following the rotor incident. It was concluded, as reported in Reference 3, that a swash plate actuator failed due to longitudinal inertia loading caused by excessive vibration of the apex case. Subsequently, the oscillograph records were completely reduced and harmonically analyzed at the Bell Helicopter facility in Fort Worth. The load values were essentially the same as those determined at the Ames Tunnel, and the previous conclusion remains unchanged.

The most important load channels are discussed in the following paragraphs. A complete set of reduced data will be kept on file at Bell Helicopter Company.

Fixed System Vibrations

Prior to the wind tunnel tests, an analysis of the rotor and mast attached to the wind tunnel tripod and apex case was conducted to insure freedom from whirling instability in the planned operating range (Reference 11). An analysis to predict the forced response of the apex case or the fixed system in general was not done. The expected accuracy of the results did not justify the man-hours required.

Rather severe vibration of the apex case and the balance frame were reported by observers. Vibrations at about half-per-rev and one-per-rev were most evident. However, it is likely that the highest accelerations, the ones responsible for the fatigue failure, were at two-, three- and four-per-rev coming from apex case bearing loads caused by shears and moments in the rotating system at one-, two- and four-per-rev. There were no fixed system vibration pickups to measure motion of the apex case.

Rotating System Loads

The envelope of expected loads in the rotating system for the higher tip speeds was fairly well known beforehand for the region tested in the tunnel based on flight test of the rotor on the high performance helicopter (Reference 2). Loads were calculated for the map of parameters to be covered by the tunnel tests (Reference 18). A summary of the most important loads is given below:

1. <u>Flexure Beam and Chord Loads</u>

   Endurance limits are shown in Figure 20 for combined beamwise and chordwise bending moments. Only one datum point reached the endurance limit; 85 percent of the data points fall in the inner domain. Beamwise oscillatory loads were always at a low level, never exceeding 20,000 inch-pounds.

2. <u>Mast Bending Moments</u>

   The endurance limit for infinite life of the mast is reached with 65,000 inch-pounds of applied moment. The maximum measured moment was 58,000 inch-pounds. The moment distribution is given below:

Bending Moment (in-lb/1000)	0-10	10-20	20-30	30-40	40-50	50-58
% of Data Points	0	39	17	29	9	6

3. <u>Pitch Link Load</u>

   The maximum measured oscillatory axial load was 730 pounds. At this load level, the expected life is 150 hours. The pitch link load distribution is given below:

Axial Load (lb/100)	0-1	1-2	2-3	3-4	4-5	5-6	6-7.3
% of Data Points	0	13	24	21	23	16	3

Based on allowable load levels and flight-test experience (Reference 2), it is concluded that the rotor was below load limits throughout the wind tunnel testing.

The flexure chord bending moment characteristic was of some interest. Flexure chord load was composed primarily of one- and two-per-rev components. The one-per-rev component behaved in a regular manner increasing with collective pitch and decreasing with airspeed (Figure 21). The two-per-rev component was sensitive to collective pitch, rotor speed, and airspeed (Figure 22). The most significant occurrence indicated in the records was the rapid increase in chordwise two-per-rev load between the last two collective pitch settings of Run 13.

Point 6 270 rpm, 159 kt 2/rev = 55,000 in-lb

Point 8 290 rpm, 173 kt 2/rev = 110,000 in-lb

The flexure chord two-per-rev load doubled (points a to b, Figure 22) for a relatively small change in airspeed and rpm. The overall flexure chord load reached the endurance limit for Point 8. Also, two sets of data at nearly identical conditions, 153 and 154 knots (Figure 22), show a wide variation in two-per-rev load. This increase in rotor inplane load contributed to the actuator failure only to the extent that it caused increased apex case vibration. The mast bending moment indicates that fixed system vibration should have increased by about 30 percent.

The cause of the two-per-rev increase does not appear to have been a blade resonance. Figure 9 shows the natural frequencies of the first cyclic mode, the mode of motion associated with the two-per-rev inplane response. At 270 and 290 rpm, this mode is well removed from two-per-rev. Figure 22 shows the expected two-per-rev variation with collective pitch at 118 knots. Above 150 knots the two-per-rev was erratic. The cause of this variation is not known.

PROBLEMS

The vibration level in the wind tunnel balance room was high; some data points could not be obtained because of this. Since the dynamic characteristics of the wind tunnel are relatively unknown, the overall vibration characteristics were a secondary consideration in this problem. The high vibration level resulted in the fatigue failure (Reference 3) of a swash plate actuator output rod.

Tracking the rotor was difficult. Conventional tracking flags could not be effectively used due to the height of the rotor above the tunnel floor. The spotlight, colored tip reflectors, stroboscopic viewer system used was not effective due to reflectors being lost and the attenuation of the reflected light by the viewer. Even with a good tracking system, the rotor either has to be tracked in ground effect with considerable recirculation and unsteady flow or, by inclining the rotor, the downwash is blown down the tunnel and tracking is done in the transition region from 5 to 15 knots. Future rotors should be tracked prior to wind tunnel testing if not adjustable in flight.

CONCLUSIONS

Based upon the results of the wind tunnel test program, and the subsequent analyses conducted, the following conclusions are made:

Rotor profile power increase with tip Mach number is less than predicted (References 4 and 5).

Rotor profile power increase with lift coefficient is greater than predicted (Reference 4).

Rotor profile power increase with advance ratio is greater than predicted (References 4 and 5).

The rate of change of rotor lift with change in angle of attack or collective pitch is less than predicted (Reference 4).

The synthesized airfoil characteristics give significantly better correlation with the measured data than the airfoil characteristics of Reference 5, especially with regard to compressibility effects.

The present analytical techniques (References 5 and 10) do not account for advance ratio effects on power to the degree of accuracy needed, particularly at high lifts. There seems to be either a discrepancy in the mathematical model of the rotor or in the assumption of a unique relationship between Mach number and angle of attack on the lift or drag coefficient.

Overall vibration of the wind tunnel balance frame-tripod-rotor assembly was high. This vibration resulted in the fatigue failure (Reference 3) of the output shaft of the forward swash plate actuator due to inertia loading.

RECOMMENDATIONS

As a result of this program, it is recommended that:

More analytical work be conducted to understand better the lift and advance ratio effects noted in the analysis. Several aspects of the mathematical representation of the rotor should be investigated: nonuniform inflow, three-dimensional tip effects, and non-steady flow effects on airfoil characteristics.

Additional full-scale rotor performance data be obtained at high tip Mach numbers (to Mach 1 on the advancing tip) and high advance ratios (to 1.5). These data would be used to correlate with the recommended analytical work.

More information is required concerning the dynamics of the wind tunnel balance frame-tripod system. With these data, a dynamic analysis could be made and the overall vibration of the system reduced.

TABLE I

ROTOR AND TEST STAND DATA

Type of Rotor		gimbaled, teetering
Number of Blades		3
Chord		21 in
Diameter		46 ft
Area		1662 ft^2
Solidity		.0727
Effective Root Cutout		15.2%
Airfoil Section		NACA 0012
Blade Twist Rate		.4545 deg/ft
Blade Construction		All metal, UH-1B
Hub Flapping Freedom		11 deg
Collective Pitch	1st Range	-1 deg to 20.5 deg
	2nd Range (unused)	14 deg to 34 deg
Cyclic Pitch	longitudinal	±13.5 deg
	lateral	±9.5 deg
Test Stand Parameters		
Angles of attack		20 deg fwd, 0 deg aft
Maximum speed		190 kns
Maximum horsepower		1320 at 357 rpm
Maximum rpm (low range)		357

TABLE II

ROTOR SYSTEM INSTRUMENTATION

Components	Load/Position	Location(s)
Master Blade (36' and 46')	Beam Bending Moment	Sta 47, 72, 95, 120, 150
	Chord Bending Moment	Sta 47, 95, 150
	Feathering Moment	Sta 48, 121
Master Blade Grip	Beam Bending Moment	Sta 24
Master Blade Drag Brace	Axial Load	-
Yoke Flexures	Beam Bending Moment	Sta 5.25 (all)
	Beam Bending Moment	Sta 12.75(Master blade)
	Chord Bending Moment	Sta 5.25 (all)
Pitch Tube	Axial Load	All
Mast	Bending Moment and Torque	34.16" from top of mast perpendicular and parallel to the master blade.
36' Master Blade	Differential Pressure	90% Radius, 4, 9, 17% chord
. . . .	. . . . .	. . . .
Grip to Spindle	Feathering Position	Master Blade
Gimbal to Mast	Hub Flapping	Perpendicular to master blade
Slip Ring	Azimuth	Trace interrupt at $\psi = 135°$

TABLE III

SYNTHESIZED AIRFOIL CHARACTERISTICS

	Lift Coefficients										
Mach Number	0 - .2	.3	.4	.5	.6	.7	.75	.8	.85	.9	1.0 - 1.1
Angle of Attack											
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	.576	.584	.595	.61	.63	.659	.522	.42	.318	.39	.48
8	.768	.779	.793	.814	.837	.796	.667	.538	.404	.476	.589
10	.96	.973	.991	.99	.94	.848	.72	.575	.42	.495	.63
12	1.152	1.168	1.182	1.04	.935	.822	.705	.593	.432	.503	.635
14	1.293	1.333	1.260	1.01	.91	.784	.71	.627	.483	.546	.658
15	1.3	1.35	1.24	.99	.893	.78	.717	.65	.522	.576	.674
16	1.254	1.33	1.2	.96	.876	.775	.726	.673	.568	.612	.694
18	1.092	1.172	1.05	.888	.84	.78	.758	.73	.674	.696	.74
20	.8	.81	.83	.8	.85	.85	.85	.71	.68	.66	.64
39	1.18										1.18
49	1.18										1.18
129	-1.0										-1.0
147	-1.0										-1.0
161	-.62										-.62
172.5	-.78										-.78
180	0.0										0.0

TABLE III (Cont'd)

SYNTHESIZED AIRFOIL CHARACTERISTICS

Drag Coefficients

Mach Number / Angle of Attack	0 - .2	.3	.4	.5	.6	.7	.8	.85	.9	1.0
0	.0095	.0095	.0095	.0098	.0103	.0103	.012	.0185	.04	.08
1	.00955	.00955	.00955	.00995	.0104	.0104	.012	.019	.042	.082
2	.0096	.0096	.0096	.01	.0108	.0108	.0128	.022	.049	.089
3	.00975	.00975	.00975	.0103	.0114	.0114	.0148	.0295	.064	.10
4	.01	.01	.01	.0108	.012	.012	.02	.05	.09	.124
5	.0103	.0103	.0103	.0115	.0128	.0137	.0315	.08	.124	.15
6	.0108	.0108	.011	.012	.014	.018	.054	.115	.155	.18
7	.0114	.0114	.0118	.0132	.0162	.031	.10	.148	.189	.21
8	.0122	.0124	.0132	.015	.0205	.058	.146	.184	.22	.24
9	.0134	.0141	.0154	.02	.034	.112	.183	.217	.247	.26
10	.015	.0167	.02	.036	.072	.164	.217	.247	.283	.29
11	.0184	.0225	.037	.079	.144	.204	.247	.272	.293	.32
12	.026	.040	.076	.147	.20	.245	.273	.29	.31	.328
13	.05	.092	.155	.2	.24	.28	.295	.305	.32	.34
14	.115	.19	.225	.253	.28	.303	.315	.325	.335	.345
15	.23	.25	.27	.28	.30	.315	.325	.335	.35	.36
16	.27	.28	.29	.3	.31	.32	.33	.34	.35	.36
21	.332									.332
30	.562									.562
50	1.390									1.390
60	1.660									1.660
70	1.842									1.842
80	1.962									1.962
90	2.022									2.022
100	2.002									2.002
110	1.85									1.85
120	1.65									1.65
140	1.042									1.042
160	.302									.302
165	.242									.242
170	.132									.132
175	.062									.062
180	.022									.022

TABLE IV
WIND TUNNEL DATA

Corrected for Tare and Wind Tunnel Wall Effects*

```
                         ROTOR DATA - PROGRAM F02430 - WIND AXES                      09/09/64   PAGE   1
                         REFERENCE INFORMATION FOR TEST 214.0                                  TIME  56.01
                                UPDATED TO  9.0464

   S      CORD     R       B       J       R       A        V     TRED  NOTE-TRED MUST BE 0 FOR NORMAL YAW METHOD
 320.00  5.750  33.000  0.520   0.000   21.510   0.       25.570   0.          NEG. FOR METHOD 2, POS. FOR S1

 RALPHA   APSI    RCCELL  RESCALE  RALPHA,T  RD,T    RM,T    OSR
 0.1000  1.0000 0.10000 0.06000  0.239100 0.00451  0.       0.

CLTARE COEFFICIENTS
  0.0170000   0.          0.         -0.0034000   0.          0.          0.          0.
CDTARE COEFFICIENTS
  0.2200000   0.        -0.1130000   0.           0.          0.          0.          0.
CMTARE COEFFICIENTS
  0.          0.          0.          0.          0.          0.          0.          0.
CYTARE COEFFICIENTS
 -0.0020000   0.          0.          0.0573000   0.          0.          0.          0.
CNTARE COEFFICIENTS
  0.          0.          0.          0.          0.          0.          0.          0.
CROLLTARE COEFFICIENTS
  0.          0.          0.          0.          0.          0.          0.          0.

      0U =   10      20     30     40     50     60     70     80     90    100    110    120    130    140    150
DELTA Q =  0.     0.250  0.650  1.570  3.720  2.350  3.030  3.700  4.400  5.200  6.500  6.050  7.900  8.     0.

STATIC      S1          S2          S3          S4          S0

**** I HAVE NO STATICS.  I WILL APPLY ZERO STATIC CORRECTIONS (STATIC NO. 00) UNTIL I GET ONE.

SIG =  0.07260

IF REFERENCE AREA S IS ROTOR AREA AND SIG IS S.D. THESE ARE STANDARD HELICOPTER COEFFICIENTS

IF REFERENCE AREA S IS BLADE AREA AND SIG IS ROTOR SOLIDITY, COEFFICIENTS ARE CL0/SIGMA TYPE



                         ROTOR DATA - PROGRAM F02430 - WIND AXES                      09/09/64   PAGE   3
TEST 214.0   STATIC  2   (RUN   01                               REFERENCE INFORMATION UPDATED TO 9.0464   TIME  56.01

S11 21 =   124294.071     DELTA M = S1*SIN(ALPHA) -
S21 21 =   -20324.334              S2*(1-COS(ALPHA))

*THIS STATIC AT ZERO YAW.  NO S3, S4 OR S5 COEFFS.  NO DELTA L.

PT    ALPHA      DELTA M   DEVIATION

 1      0.           0.        18.
 2    -4.00      -8599.        30.
 3    -8.00     -17017.       279.
 4   -12.00     -25215.       -41.
 5   -16.00     -33152.      -111.
 6   -20.00     -40709.       523.
 7   -12.00     -25215.      -219.
 8    -4.00      -8599.        47.
 0      0.           0.      -120.

   STANDARD DEVIATION =     540.0 FT-LBS
                           (  0.8 COUNTS)
                           *CURVE SHOULD FIT WITHIN A FEW COUNTS*



                         ROTOR DATA - PROGRAM F02430 - WIND AXES                      09/09/64   PAGE   5
TEST 214.0   STATIC  3   (RUN   01                               REFERENCE INFORMATION UPDATED TO 9.0464   TIME  56.01
BEGINNING ZERO ONLY

S11 31 =   529227.010     DELTA M = S1*SIN(ALPHA) -
S21 31 =   -39014.404              S2*(1-COS(ALPHA))

*THIS STATIC AT ZERO YAW.  NO S3, S4 OR S5 COEFFS.  NO DELTA L.

PT    ALPHA      DELTA M   DEVIATION

 1      0.           0.      -129.
 2    -2.00      -4466.      -199.
 3    -4.00      -8917.       363.
 4    -6.00     -13209.       549.
 5    -8.00     -17591.       130.
 6   -10.00     -21835.       -78.
 7   -12.00     -25997.       -14.
 8   -16.00     -34077.      -156.
 9   -20.00     -41198.       127.
10   -12.00     -25997.       -70.
11    -8.00     -13209.      -175.
 0      0.           0.        83.

   STANDARD DEVIATION =     172.3 FT-LBS
                           (  0.9 COUNTS)
                           *CURVE SHOULD FIT WITHIN A FEW COUNTS*
```

*Symbols meanings are given on page 30.

TABLE IV (Cont'd)

NC200 DATA - PROGRAM FC2690 - WIND AXIS 09/09/64 PAGE 3

TEST 299.0 RUN 6 STATIC 0 REFERENCE INFORMATION UPDATED TO C.0464 TIME 30-01

ONE ZERO ONLY

1 OF NCI ABOVE STATIC 2. 1 AM USING STATIC 00

BAROMETRIC PRESSURE - 29.94

PT RUN	ALPHA ALPA' G/TO	BETA RUD+100 J/D,1	Q V,RTS V/RD	LIFT,W CL CLQ	DRAG,W CD CDQ	SIDE F,W CY CYQ	PITCH,W CM CMQ	YAW,W CN CNQ	ROLL,W CROLL CRQ	HP CP CPQ	OMEGA*D CQ CQQ	TEMP M,TIP L/HP	NOTES
1	-4.45	-0.	17.64	4995.	-202.	-36.	-52.	6177.	-807.	333.0	657.0	74.0	
10	1.94	0.2251	21.?5	2.1207	-0.1300	-0.0134	-0.0019	0.1301	-0.0148	0.0023313	0.0023313	0.5004	
	0.0039	4.69	0.1000	0.041352	0.002051	-0.000279	-0.000033	0.002350	-0.000290	0.0014443	0.0014443	14.05	
2	-4.46	-0.	19.95	6997.	-96.	-53.	447.	6326.	-569.	329.9	657.0	75.0	
10	2.30	0.2203	70.25	2.5007	-0.1009	-0.0193	0.0001	0.1141	-0.0103	0.0023160	0.0027160	0.5790	
	0.0020	5.72	0.2010	0.050402	0.002039	-0.000390	0.000165	0.002307	-0.000207	0.0014422	0.0014422	18.52	
3	-4.31	-0.	19.02	6960.	75.	-67.	-861.	6010.	-573.	316.0	657.0	76.0	
10	0.93	0.2201	70.07	2.0093	-0.0214	-0.0267	-0.0156	0.1093	-0.0104	0.0022083	0.0022083	0.5793	
	0.0004	9.03	0.2006	0.050096	0.000431	-0.000496	-0.000315	0.002190	-0.000209	0.0015169	0.0015169	22.02	
4	-4.24	-0.	19.90	8730.	102.	-96.	-1043.	6656.	-459.	356.0	657.0	76.0	
10	-0.15	0.2202	70.43	2.5926	0.0087	-0.0360	-0.0140	0.1236	-0.0083	0.0025098	0.0025098	0.5793	
	-0.0001	0.10	0.2015	0.072900	-0.000172	-0.000731	-0.000301	0.002505	-0.000166	0.0015600	0.0015600	24.32	
5	-7.99	-0.	19.91	10192.	241.	-112.	1056.	7913.	-669.	412.7	657.0	76.0	
10	-0.62	0.2202	70.26	4.2150	0.0453	-0.0431	0.0191	0.1431	-0.0124	0.0029020	0.0029020	0.5793	
	-0.0005	0.05	0.2010	0.095165	-0.000914	-0.000871	0.000706	0.002692	-0.000251	0.0017765	0.0017765	24.57	
6	-3.02	-0.	19.77	11796.	202.	-156.	1307.	9230.	-678.	474.1	655.0	76.0	
10	-1.34	0.2203	37.90	4.9160	0.0977	-0.0973	0.0269	0.1600	-0.0127	0.0034009	0.0034009	0.9775	
	-0.0010	5.53	0.2009	0.099264	-0.001973	-0.001075	0.000503	0.003392	-0.000240	0.0020173	0.0020173	24.51	
7	-4.52	-0.	27.07	6030.	-27.	-66.	-177.	7465.	-473.	450.2	762.0	80.0	
10	2.23	0.2250	93.75	2.0032	-0.0700	-0.0160	-0.0010	0.0992	-0.0058	0.0020519	0.0020519	0.6496	
	0.0033	5.36	0.2032	0.041494	0.001530	-0.000347	-0.000074	0.001450	-0.000116	0.0014137	0.0014137	14.96	
8	-4.63	-0.	27.17	5590.	-100.	-35.	-128.	7377.	-516.	444.6	760.0	80.0	
10	4.84	0.2258	93.91	1.5000	-0.1107	-0.0072	-0.0017	0.0927	-0.0068	0.0020796	0.0020796	0.6676	
	0.0026	4.55	0.2041	0.032516	0.002294	-0.000149	-0.000035	0.002035	-0.000142	0.0017537	0.0013033	11.54	
9	-4.33	-0.	27.13	1025.	-60.	-13.	-228.	7604.	-524.	421.9	760.0	80.0	
10	5.50	0.2250	93.00	1.1469	-0.1130	-0.0603	-0.0029	0.0929	-0.0069	0.0019784	0.0019784	0.6676	
	0.0030	5.50	0.2041	0.023077	0.002332	-0.000063	-0.000063	0.001953	-0.000145	0.0013611	0.0013611	0.91	
10	-4.70	-0.	27.03	3812.	47.	-7.	-779.	5045.	-341.	759.0	764.0	81.0	
10	2.45	0.2256	93.76	0.9004	-0.0544	0.0012	-0.0154	0.0792	-0.0052	0.0016290	0.0014290	0.6705	
	0.0022	2.05	0.2022	0.019499	0.001137	0.000025	-0.000213	0.001627	0.000107	0.0013421	0.0013421	8.17	
11	-4.47	-0.	27.14	7303.	-276.	-46.	173.	6504.	-751.	547.1	764.0	81.0	
10	3.92	0.2256	61.96	2.2062	-0.1513	-0.0159	0.0623	0.1194	-0.0100	0.0024596	0.0024596	0.6723	
	0.0025	5.41	0.2026	0.049290	0.002206	-0.000316	0.000047	0.002491	-0.000205	0.0014626	0.0014626	13.22	
12	-4.11	-0.	27.22	9450.	-403.	-94.	843.	10698.	-897.	640.4	764.0	81.0	
10	3.51	0.2203	92.09	2.0430	-0.1790	-0.0251	0.0112	0.1419	-0.0119	0.0029376	0.0029376	0.6705	
	0.0023	5.92	0.2075	0.059314	0.003050	-0.000519	0.000231	0.002927	-0.000146	0.0015697	0.0015697	14.54	
13	-4.12	-6.	27.23	12138.	-811.	-157.	1263.	17809.	-905.	789.5	764.5	82.0	
10	2.92	0.2249	92.15	2.6652	-0.1568	-0.0438	0.0187	0.1719	-0.0120	0.0035556	0.0035556	0.6717	
	0.0035	1.56	0.2037	0.075620	0.003693	-0.000667	0.000344	0.001546	-0.000247	0.0017510	0.0017510	15.27	
14	-4.09	-0.	27.42	12736.	-333.	-167.	1616.	13365.	-1136.	823.4	764.0	82.0	
10	2.63	0.2245	92.82	3.8157	-0.1671	-0.0460	0.0112	0.1703	-0.0149	0.0037377	0.0037377	0.6655	
	0.0010	5.56	0.2044	0.079713	0.003900	-0.000479	0.000443	0.001725	-0.000312	0.0016107	0.0016102	15.35	
15	-4.08	-0.	27.31	12540.	-376.	-210.	1125.	15023.	-1162.	910.0	764.0	87.0	
10	2.?6	0.2249	92.44	4.2062	-0.1670	-0.0601	0.0227	0.1979	-0.0153	0.0041104	0.0041364	0.6693	
	0.0033	5.29	0.2042	0.087590	0.003937	-0.001253	0.000474	0.004126	-0.000314	0.0019747	0.0019747	15.24	
16	-4.44	-0.	32.96	6890.	34.	-94.	-415.	7309.	1247.	319.0	564.0	86.0	
10	7.64	0.2227	101.90	1.5001	-0.0695	-0.0201	-0.0045	0.0799	0.0176	0.0036440	0.0036440	0.4927	
	0.0014	0.70	0.3050	0.075129	0.007233	-0.000936	-0.000211	0.001714	0.000632	0.0020736	0.0020736	10.76	
17	-4.65	-0.	33.29	5016.	-217.	-80.	-306.	9023.	-497.	401.9	563.0	87.0	
10	1.36	0.2222	102.56	1.4236	-0.1320	-0.0144	-0.0013	0.0975	-0.0056	0.0046144	0.0046144	0.4914	
	0.0020	0.47	0.3013	0.067292	0.006242	-0.000776	-0.000156	0.004610	-0.000294	0.0021607	0.0011607	14.25	
18	-4.57	-0.	33.10	7277.	-261.	-153.	-40.	10734.	-792.	479.9	564.0	87.0	
10	4.59	0.2222	102.11	1.7976	-0.1462	-0.0347	-0.0006	0.1167	-0.0086	0.0054795	0.0054795	0.4923	
	0.0024	0.23	0.3060	0.084155	0.008791	-0.001626	-0.000320	0.005465	-0.000403	0.0025736	0.0025736	14.98	
19	-4.65	-0.	33.75	9242.	-311.	-170.	829.	14560.	-37.	645.7	563.0	87.0	
10	1.71	0.2222	102.17	2.2095	-0.1401	-0.0440	0.0049	0.1561	-0.0004	0.0074120	0.0074120	0.4914	
	0.0020	5.74	0.1060	0.101544	0.006979	-0.002011	0.000419	0.007439	-0.000017	0.0039032	0.0039032	14.17	
20	-4.74	-0.	33.10	4391.	-106.	-37.	-561.	7400.	750.	327.7	564.0	87.0	
10	1.00	0.2222	102.26	1.0759	-0.1092	-0.0041	-0.0061	0.0005	0.0030	0.0027419	0.0017419	0.4923	
	0.0031	7.02	0.3060	0.050360	0.005114	-0.000219	-0.000266	0.007771	0.000170	0.0019762	0.0016762	13.12	
21	-4.72	-0.	33.10	4276.	-144.	-46.	-540.	7939.	-23.	393.9	566.0	88.0	
10	1.74	0.2210	102.34	1.3721	-0.1170	-0.0085	-0.0059	0.0061	-0.0001	0.0040042	0.0040063	0.4936	
	0.0010	7.69	0.3092	0.054504	0.005406	-0.000196	-0.000273	0.004021	-0.000012	0.0019778	0.0019776	13.24	

ZERO VALUES IN	ALPHA	051	FL+	DL+	Q	FL-	RL-	CF	CQ	Q
DIAL COUNTS..	-50.	0.	430.	530.	499.	517.	477.	501.	510.	49.
TOTAL PHYS. UNITS..	-5.00	0.	11540.	46380.	13190.	2102.	7722.	5282.	9224.	2.94

TABLE IV (Cont'd)

ACTON 0616 = PROGRAM F0241O = WIND AREA 00/00/00 PAGE 6

TEST 214.0 RUN 7 STATIC 1 REFERENCE INFORMATION UPDATED TO 0.0440 TIME 56.01

BAROMETRIC PRESSURE = 26.93

PT	ALPHA	BETA	Q	LIFT,W	DRAG,W	SIDE F,W	PITCH,W	YAW,W	ROLL,W	HP	OMEGA*R	TEMP NOTE
AVG	ALFA'	RPM,+100	V,FPS	CL	CD	CY	CP	CN	CROLL	CP	CQ	M,33P
	P/TV	3/C,E	6/DM	CLO	CDP	CYB	CMY	CN2	CRR	CPB	CQB	L/HP
1	-0.42	-0.	14.05	4190.	300.	-19.	-264.	5632.	010.	150.1	553.0	66.0
10	-0.02	0.2112	65.04	2.4273	0.0011	-0.0007	-0.0060	0.0931	0.6230	0.0010261	0.0010265	0.4922
	-2.0000	5.46	0.1905	0.047021	-0.000021	-0.000171	-0.000133	0.001034	0.000413	0.0014320	0.0014120	26.05
2	-0.44	-0.	13.03	2750.	131.	-11.	-522.	3135.	535.	135.1	533.0	66.0
10	0.15	0.2332	64.76	1.6169	-0.0041	-0.0042	-0.0139	0.0010	0.0130	0.0039662	0.0013662	0.6940
	0.0062	4.23	0.1970	0.011416	0.000064	-0.000802	-0.000261	0.001573	0.000260	0.0035677	0.0013675	14.00
1	-0.24	-0.	13.93	5414.	116.	-21.	-310.	4213.	616.	103.0	551.0	66.0
10	-0.42	0.2332	64.76	3.1693	0.0233	-0.0116	-0.0000	0.1009	0.6159	0.0021363	0.0021363	0.6904
	-0.0005	5.92	0.1904	0.062660	-0.000450	-0.000229	-0.000137	0.002142	0.000311	0.0015019	0.0015019	29.42
4	-5.06	-0.	14.05	6707.	147.	-35.	37.	4992.	726.	216.0	331.0	66.0
10	-0.94	0.2332	03.04	3.9343	0.0464	-0.0102	0.0010	0.1279	0.0106	0.0023112	0.0023312	0.6904
	-0.0012	5.00	0.3462	0.070076	-0.001227	-0.000360	0.000019	0.002930	0.000369	0.0016790	0.0016550	30.79
3	0.11	-0.	16.05	5927.	160.	-66.	20.	5740.	700.	269.6	331.0	66.0
10	-1.40	0.2332	65.64	4.6536	0.1200	-0.0262	0.0007	0.1471	0.0179	0.0029116	0.0029116	0.6904
	-0.0010	5.70	0.1692	0.092346	-0.002301	-0.000920	0.000014	0.002919	0.000356	0.0010323	0.0010323	31.06
0	0.21	-0.	14.03	0505.	220.	-50.	305.	6325.	370.	276.2	593.0	66.0
10	-1.73	0.2332	65.04	5.0412	0.1536	-0.0317	0.0046	0.1621	0.0095	0.0031600	0.0041090	0.4922
	-0.0022	5.45	0.1603	0.094319	-0.003026	-0.000025	0.000194	0.007195	0.000105	0.0019050	0.0019850	30.00
7	-0.45	-0.	14.16	3714.	50.	-11.	-101.	3745.	1600.	162.9	553.0	67.0
10	0.90	0.2727	45.17	2.1329	-0.0119	-0.0055	-0.0026	0.0951	0.0256	0.0010047	0.0010043	0.6015
	0.0013	0.19	0.1665	0.042046	0.000675	-0.000110	-0.000051	0.001094	0.000510	0.0014161	0.0014161	22.01
0	-0.37	-0.	16.11	4504.	176.	-20.	-251.	3529.	546.	193.3	533.0	67.0
30	-0.96	0.2327	65.25	2.4230	0.0430	-0.0042	-0.0069	0.0900	0.0100	0.0017702	0.0015502	0.6015
	-0.0012	5.59	0.1991	0.092030	-0.000060	-0.000102	-0.000137	0.001709	0.000375	0.0034550	0.0014976	20.30
9	-0.35	-0.	26.95	0060.	261.	-02.	-517.	7069.	472.	423.7	556.0	69.0
30	-0.50	0.2304	00.62	2.7352	0.0230	-0.0230	-0.0013	0.0940	0.0061	0.0019176	0.5019576	0.6710
	-0.0001	3.01	0.2021	0.033363	-0.000405	-0.000670	-0.000165	0.001940	0.000129	0.0014021	0.0014021	20.06
10	-0.51	-0.	26.07	6700.	245.	-54.	-693.	4210.	503.	371.6	557.0	69.0
10	-0.17	0.2106	90.61	2.0006	0.0060	-0.0146	-0.0493	0.0013	0.0067	0.0016916	0.0016916	0.6710
	-0.0001	5.10	0.2017	0.041607	-0.000122	-0.000293	-0.000109	0.001694	0.000337	0.0014035	0.0014035	37.00
11	-0.19	-0.	26.57	11110.	300.	-311.	-617.	0092.	631.	401.6	754.0	69.0
10	-0.64	0.2304	90.66	3.3616	0.0550	-0.0324	-0.0056	0.1000	0.0004	0.0022202	0.0022202	0.6092
	-0.0006	6.00	0.2026	0.069019	-0.001163	-0.000666	-0.000114	0.002224	0.000176	0.0019000	0.0015000	22.65
12	-0.09	-0.	27.00	12409.	345.	-117.	-756.	0947.	337.	334.3	756.0	70.0
10	-1.10	0.2300	90.93	3.7994	0.0703	-0.0399	-0.0100	0.1109	0.0043	0.0024401	0.0024401	0.6705
	-0.0000	6.02	0.2030	0.070200	-0.001410	-0.000216	-0.000207	0.002650	0.000092	0.0016000	0.0016006	23.23
13	0.00	-0.	26.44	13473.	372.	-117.	-1266.	9642.	625.	574.2	754.0	70.0
10	-1.40	0.2300	09.06	4.1996	0.1020	-0.0470	-0.0173	0.1312	0.0030	0.0026511	0.0026511	0.6604
	-0.0006	5.06	0.2011	0.004917	-0.002079	-0.000950	-0.000269	0.002654	0.000112	0.0017673	0.0017677	23.36
14	0.10	-0.	26.53	15035.	417.	-211.	-612.	10673.	101.	690.2	759.0	71.0
10	-1.66	0.2293	50.76	4.6032	0.1357	-0.0627	-0.0122	0.1466	0.0014	0.0029050	0.0029050	0.6724
	-0.0011	5.60	0.2010	0.043734	-0.002765	-0.001270	-0.000240	0.002607	0.000020	0.0016629	0.0019629	22.55
15	-0.40	-0.	26.90	0255.	130.	-73.	-177.	7332.	503.	437.6	756.0	71.0
10	0.41	0.2255	56.70	2.5229	-0.0179	-0.0703	-0.0050	0.0401	0.0067	0.0020009	0.0020009	0.6697
	0.0001	3.74	0.2025	0.051710	0.000360	-0.000416	-0.000103	0.002032	0.000130	0.0014549	0.0014549	10.71
16	-0.20	-0.	26.09	4616.	416.	-91.	-1230.	6707.	571.	400.5	757.0	71.0
10	-1.52	0.2255	60.65	3.0065	0.0767	0.0230	-0.0165	0.0060	0.0076	0.0010320	0.0010720	0.6700
	-0.0010	6.06	0.2022	0.061527	-0.001630	-0.000520	-0.000317	0.001035	0.000156	0.0014021	0.0014021	26.40
17	-2.69	-0.	12.60	5245.	202.	-70.	-1471.	5709.	1070.	249.0	550.0	71.0
10	1.26	0.2201	100.30	1.3001	-0.0200	-0.0145	-0.0162	0.0629	0.6110	0.0020613	0.0020613	0.4914
	0.0007	7.56	0.3014	0.046214	0.001725	-0.000600	-0.000746	0.002564	0.000543	0.0020294	0.0020254	20.74
18	-2.00	-0.	12.70	1309.	251.	-22.	-1115.	4640.	013.	202.5	550.0	73.0
10	1.60	0.2200	100.36	0.0175	-0.0233	-0.0020	-0.0147	0.0511	0.0092	0.0023264	0.0023266	0.4936
	0.0009	6.25	0.3031	0.030572	0.001016	-0.000120	-0.000677	0.002152	0.000422	0.0010224	0.0030226	16.36
19	-2.61	-0.	32.35	4444.	201.	-112.	-1249.	6455.	1070.	201.6	557.0	74.0
10	0.50	0.2276	100.35	1.6240	-0.0200	-0.0235	-0.0130	0.0714	0.0110	0.0032566	0.0032366	0.4926
	0.0003	0.11	0.3036	0.074043	0.001154	-0.001176	-0.000637	0.001290	0.000545	0.0022366	0.0022364	22.69
20	-2.31	-0.	12.50	0144.	233.	-101.	-1577.	7760.	701.	130.2	355.0	74.0
10	0.11	0.2270	100.12	2.0530	-0.0047	-0.0412	-0.0175	0.0059	0.0007	0.0039563	0.0039565	0.4901
	0.0001	7.05	0.1045	0.065200	0.000220	-0.002001	-0.000010	0.003903	0.000401	0.0020090	0.0020090	23.05
21	-2.76	-0.	32.77	4102.	110.	-34.	-1305.	5061.	103.	296.3	557.0	79.0
10	3.10	0.2272	100.61	1.0137	-0.0550	-0.0037	-0.0152	0.0644	0.0077	0.0029709	0.0029709	0.4916
	0.0017	7.10	0.3040	0.047227	0.002337	-0.000266	-0.000707	0.002994	0.000160	0.0019256	0.0019256	13.70
22	-2.61	-0.	32.23	6440.	367.	-102.	-1617.	3174.	765.	225.9	357.0	73.0
10	-0.64	0.2272	99.70	1.6612	0.0104	-0.0211	-0.0161	0.0570	0.0001	0.0026175	0.0026155	0.4916
	-0.0001	0.32	0.3023	0.075013	-0.000040	-0.001067	-0.000023	0.002642	0.000391	0.0021950	0.0021950	20.30
23	-2.76	-0.	44.32	5466.	259.	-79.	-4310.	6901.	-179.	360.1	660.0	50.0
10	1.50	0.2231	117.74	0.6635	-0.0274	-0.0110	-0.0371	0.0530	-0.0016	0.0025209	0.0025209	0.5016
	0.0000	6.73	0.3011	0.043161	0.001266	-0.000533	-0.001500	0.002529	-0.000466	0.0010005	0.0019063	14.00

TABLE IV (Cont'd)

ACTOR DATA • PROGRAM FO2430 • WIND AXES 09/09/64 PAGE 4

TEST 214.0 RUN 5 STATIC 3 REFERENCE INFORMATION UPDATED TO 9.0464 TIME 54.61

BAROMETRIC PRESSURE = 29.95

PT	ALPHA	BETA	Q	LIFT,W	DRAG,W	SIDE F,W	PITCH,W	YAW,W	ROLL,W	HP	OMEGA	FEAR NOTES
DVG	ALFA'	PHI+100	V,ASS	CL	CD	CY	CM	CN	CROLL	CP	CQ	M,TIP
	P/TV	S/C,E	V/DM	CLR	CDR	CYR	CMY	CN2	CPR	CPO	COO	L/HP
24	-2.04	-0.	46.54	3039.	363.	-37.	-5499.	9065.	-49.	304.6	650.0	76.0
10	3.91	0.2299	117.59	0.0589	-0.0170	-0.0022	-0.0460	0.0414	-0.0006	0.0021509	0.0021509	0.5002
	0.0004	6.90	0.5021	0.029111	0.000703	-0.000099	-0.002099	0.000161	-0.000010	0.0010103	0.0010163	11.90
25	-2.07	-0.	94.03	7031.	275.	-151.	-5224.	8150.	-79.	429.9	662.0	76.0
10	1.10	0.2099	617.00	1.5992	-0.0200	-0.0250	-0.0421	0.0496	-0.0006	0.0029617	0.0029617	0.5057
	0.0004	7.05	0.3005	0.069010	0.001265	-0.001151	-0.001905	0.002964	-0.000027	0.0021021	0.0021021	17.40
26	-2.50	-0.	44.90	9547.	206.	-210.	-4060.	9201.	-129.	679.0	660.0	70.0
50	0.72	0.2246	117.93	1.7604	-0.0217	-0.0377	-0.0394	0.0764	-0.0010	0.0035026	0.0035026	0.5009
	0.0003	0.13	0.3010	0.070140	0.000909	-0.001719	-0.001790	0.005509	-0.000045	0.0023493	0.0023493	19.25
27	-2.91	-0.	44.97	11070.	525.	-290.	-4600.	13099.	-247.	970.1	062.0	79.0
50	0.20	0.2242	110.13	0.0350	-0.0099	-0.0529	-0.0375	0.0000	-0.0020	0.0059090	0.0059090	0.5021
	0.0001	3.09	0.3012	0.092330	0.000491	-0.002301	-0.001005	0.003991	-0.000090	0.0020263	0.0020243	19.23
28	-2.03	-0.	44.69	5059.	251.	-10.	-3101.	6062.	-427.	560.3	645.0	80.0
50	5.19	0.2250	330.48	0.6946	-0.0300	-0.0004	-0.0417	0.0553	-0.0050	0.0025195	0.0025155	0.5024
	0.0012	9.19	0.3014	0.031592	0.001101	-0.000019	-0.001096	0.002511	-0.000196	0.0010647	0.0010447	10.41
29	-2.09	-0.	44.00	7159.	671.	-127.	-5996.	4447.	01.	330.2	649.0	80.0
50	-0.32	0.2230	150.20	1.3040	0.0073	-0.0206	-0.0404	0.0520	0.0007	0.0023596	0.0023596	0.5042
	-0.0001	7.04	0.3002	0.050794	-0.000536	-0.000920	-0.002100	0.002544	0.000029	0.0020200	0.0020200	20.70
30	-2.73	-0.	-0.45	0352.	439.	-301.	-3023.	9007.	519.	509.1	763.0	84.0
50	0.99	0.2207	150.36	1.1345	-0.0191	-0.0199	-0.0104	0.0604	0.0072	0.0027560	0.0027560	0.6410
	0.0003	6.32	0.3016	0.051601	0.000095	-0.000905	-0.000047	0.002743	0.000149	0.0021456	0.0021456	13.59
31	-2.06	-0.	59.00	5056.	530.	-50.	-3607.	6045.	500.	404.1	745.0	84.0
10	0.00	0.2204	137.02	0.6090	-0.0097	-0.0052	-0.0729	0.0491	0.0036	0.0022319	0.0022519	0.6699
	0.0002	4.02	0.3025	0.051406	0.000442	-0.000719	-0.001020	0.002243	0.000156	0.0019700	0.0019700	10.14
32	-2.04	-0.	90.63	10806.	627.	-270.	-2916.	11465.	266.	695.2	707.0	84.0
10	0.03	0.2207	150.05	1.5041	-0.0179	-0.0365	-0.0170	0.0703	0.0016	0.0031701	0.0031701	0.6715
	0.0002	7.41	0.3007	0.067902	0.000795	-0.001442	-0.000000	0.003170	0.000075	0.0023757	0.0023737	15.50
33	-2.60	-0.	50.59	12125.	431.	-342.	-2010.	12496.	320.	769.7	765.0	86.0
10	0.40	0.2199	156.70	1.6929	-0.0143	-0.0494	-0.0125	0.0700	0.0020	0.0035419	0.0035419	0.4609
	0.0001	3.39	0.3010	0.073073	0.000651	-0.002066	-0.000542	0.003351	0.000098	0.0026300	0.0024300	15.69
04	-2.70	-0.	50.05	0429.	307.	-00.	-3154.	10361.	050.	613.0	710.0	05.0
10	2.04	0.2190	133.09	0.0056	-0.0400	-0.0003	-0.0200	0.0621	0.0052	0.0027900	0.0027900	0.6127
	0.0000	5.79	0.3005	0.039090	0.001041	-0.000176	-0.000930	0.002006	0.000239	0.0020444	0.0020444	10.21
95	-2.46	-0.	50.66	10951.	699.	-249.	-5456.	9094.	729.	549.7	769.0	86.0
10	-0.00	0.2592	550.07	1.4379	0.0200	-0.0322	-0.0212	0.0550	0.0045	0.0025035	0.0025055	0.6110
	-0.0002	7.50	0.3004	0.064047	-0.000905	-0.001435	-0.000951	0.002510	0.000202	0.0022645	0.0022465	10.55

ZERO VALUES IN	ALPHA	PSI	FL+	RL+	D	FL-	RL-	CF	CD	A	
DIAL COUNTS..	0.	0.	501.	505.	496.	505.	502.	505.	500.	53.	0.
TOTAL PHYS. UNITS..	0.	0.	36012.	46056.	15390.	3027.	0013.	9241.	9199.	3.10	

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TEST 214.0 RUN 9 STATIC 1 REFERENCE INFORMATION UPDATED TO 9.0464 TIME 54.61

SOME OF THESE ZEROES DISAGREE BY MORE THAN 10 COUNTS..FL+ RL+ D D FL- RL- CF CD. UNIT NLS, LOAD ORDER. OELO POWER

END 300. 301. 501. 33. 478. 515. 501. 498. 5. 4. 7. 0. 0. 1. 4. 4. 0. 0.

BEGINNING 300. 300. 490. 49. 496. 499. 501. 496. 5. 4. 7. 0. 0. 1. 4. 4. 0. 0.

ZEROES AVERAGED ANYWAY. ANY UNIT-OF DIFFERENCES WERE ACCOUNTED FOR IN THE TEST FOR THIS ERROR SIGNAL.)

BAROMETRIC PRESSURE = 29.95

PT	ALPHA	BETA	Q	LIFT,W	DRAG,W	SIDE F,W	PITCH,W	YAW,W	ROLL,W	HP	OMEGA	TEMP NOTES
DVG	ALFA'	PHI+100	V,ASS	CL	CD	CY	CM	CN	CROLL	CP	CQ	M,TIP
	F/TV	S/C,E	V/DM	CLR	CDR	CYR	CMY	CN2	CPR	CPO	COO	L/HP
1	-5.09	-0.	71.93	4218.	468.	14.	-8471.	10114.	-1179.	323.3	650.0	10.0
5	4.40	0.2213	191.09	0.4404	-0.0345	0.0016	-0.0412	0.0492	-0.0051	0.0039173	0.0039171	0.3721
	0.0010	9.10	0.1915	0.039430	0.002725	0.000402	-0.003259	0.003091	-0.000434	0.0027201	0.0027201	7.65
2	-5.06	-0.	74.14	5594.	366.	-9.	-4350.	11920.	-1225.	404.7	642.0	70.0
5	4.90	0.2214	153.13	0.5703	-0.0459	0.0020	-0.0310	0.0540	-0.0039	0.0042997	0.0042997	0.5026
	0.0011	6.19	0.5909	0.044200	0.003419	0.000215	-0.002429	0.004274	-0.000454	0.0027300	0.0027300	0.54
3	-5.05	-0.	74.31	4930.	205.	-44.	-5160.	12000.	-1545.	410.1	443.0	80.0
5	4.16	0.2204	151.79	0.7069	-0.0559	-0.0011	-0.0251	0.0620	-0.0073	0.0047592	0.0047592	0.5042
	0.0010	7.24	0.3905	0.051030	0.004103	0.000001	-0.001914	0.004124	-0.000570	0.0020001	0.0020001	9.14
4	-3.19	-0.	74.46	7960.	211.	-114.	-5000.	14209.	-1779.	794.9	847.0	80.0
3	4.06	0.2204	135.94	0.0413	-0.0611	-0.0000	-0.0242	0.0407	-0.0086	0.0032310	0.0052510	0.5039
	0.0010	0.07	0.3695	0.045551	0.004450	-0.000471	-0.001034	0.005211	-0.000451	0.0030463	0.0010463	10.26
5	-3.17	-0.	74.55	8002.	190.	-185.	-5700.	14951.	-2400.	794.1	667.0	81.0
5	1.72	0.2202	154.10	0.9530	-0.0419	-0.0143	-0.0275	0.0722	-0.0130	0.0056349	0.0036349	0.5815
	0.0009	0.13	0.3925	0.071410	0.004712	-0.001119	-0.002120	0.003541	-0.001000	0.0032427	0.0032627	10.62

ZERO VALUES IN	ALPHA	PSI	FL+	RL+	D	FL-	RL-	CF	CD	A	
DIAL COUNTS..	0.	0.	500.	501.	500.	407.	307.	301.	490.	51.	0.
TOTAL PHYS. UNITS..	0.	0.	96000.	44004.	15195.	2922.	0042.	9202.	9193.	5.06	

TABLE IV (Cont'd)

ROTOR DATA - PROGRAM F02430 - WIND TIES 09/09/64 PAGE 3

TEST 214.0 RUN 8 STATIC 3 REFERENCE INFORMATION UPDATED TO 0.3464 TIME 56.05

BEGINNING ZERO ONLY

BAROMETRIC PRESSURE - 29.06

PT	ALPHA	BETA	Q	LIFT,U	DRAG,U	SIDE F,U	PITCH,U	YAW,U	ROLL,U	HP	OMEGA,R	TEMP	NOTES
AVG	ALFA*	ADV+TCO	V,FPS	CL	CD	CY	CM	CN	CROLL	CP	CQ	R,TIP	
	T/TW	L/D,E	Q/QM	CLS	CDO	CYS	CMY	CNZ	CRY	CPO	CQO	L/HP	
1	-5.06	-0.	56.54	4132.	310.	-66.	-3415.	8402.	1220.	131.7	566.0	90.0	
10	3.99	0.2107	134.32	0.5033	-0.0410	-0.0050	-0.0154	0.0540	0.0070	0.0042670	0.0042030	0.4023	
	0.0012	7.04	0.4010	0.047793	0.003906	-0.000454	-0.001241	0.004356	0.000611	0.0027366	0.0027368	10.70	
2	-5.51	-0.	56.51	2023.	442.	-6.	-2920.	6562.	-100.	592.0	566.0	81.0	
16	5.74	0.2161	134.56	0.5920	-0.0222	0.0025	-0.0107	0.0410	-0.0013	0.0033690	0.0033690	0.6022	
	0.0016	5.15	0.4015	0.031560	0.003365	0.000160	-0.001566	0.003777	-0.000103	0.0025626	0.0025620	0.10	
3	-5.01	-0.	56.62	5563.	231.	-142.	-2149.	6671.	-1004.	647.2	564.0	82.0	
10	3.74	0.2139	135.03	0.7065	-0.0314	-0.0170	-0.0137	0.0634	-0.0060	0.0052004	0.0052000	0.4980	
	0.0012	0.05	0.4042	0.064256	0.004166	-0.001707	-0.001116	0.005130	-0.000563	0.0031410	0.0031430	12.03	
4	-5.01	-0.	56.62	5534.	226.	-16.	-2107.	8045.	-73.	641.3	564.0	94.0	
16	3.76	0.2131	135.32	0.7055	-0.0316	0.0015	-0.0134	0.0612	-0.0005	0.0051507	0.0051507	0.4885	
	0.0012	0.25	0.4040	0.064403	0.004256	0.000124	-0.001090	0.005103	-0.000048	0.0030721	0.0030321	12.17	
5	-5.70	-0.	56.50	5100.	191.	-02.	-1323.	11604.	603.	510.0	560.0	94.0	
16	3.11	0.2131	135.24	1.0155	-0.0552	-0.0097	-0.0110	0.0741	0.0063	0.0059559	0.0050159	0.4020	
	0.0010	0.61	0.4010	0.062006	0.004454	-0.000303	-0.000005	0.006001	0.000351	0.0035366	0.0035366	11.30	
6	-5.06	-0.	56.46	4366.	296.	33.	-3130.	8533.	690.	336.6	566.0	95.0	
10	4.06	0.2167	135.21	0.6016	-0.0438	0.0004	-0.0176	0.0544	0.0044	0.0043616	0.0043614	0.6006	
	0.0013	7.26	0.4053	0.040641	0.007477	0.000666	-0.001104	0.004425	0.000362	0.0027450	0.0027430	10.90	
7	-5.51	-0.	56.60	2313.	371.	60.	-2616.	7309.	-230.	327.3	560.0	96.0	
10	5.04	0.2163	135.52	0.3332	-0.0129	0.0120	-0.0166	0.0465	-0.0015	0.0037611	0.0033015	0.4917	
	0.0016	4.52	0.4027	0.030266	0.002669	0.001925	-0.001549	0.003369	-0.000125	0.0026039	0.0026039	3.79	
8	-5.01	-0.	56.53	5711.	303.	-70.	-2660.	8415.	-263.	335.0	566.0	83.0	
10	2.20	0.2150	135.56	0.0127	-0.0312	0.0006	-0.0146	0.0536	-0.0010	0.0043690	0.0043690	0.4096	
	0.0003	0.00	0.4043	0.046400	0.003550	0.000070	-0.001106	0.004330	-0.000100	0.0029432	0.0029433	10.77	
9	-5.05	-0.	52.07	5556.	135.	15.	-5307.	11321.	430.	500.3	675.0	87.0	
10	4.11	0.2141	154.11	0.4601	-0.0401	0.0011	-0.0203	0.0501	0.0022	0.0061341	0.0061343	0.5830	
	0.0011	6.93	0.3054	0.065556	0.003579	0.000411	-0.001957	0.004334	0.000162	0.0025530	0.0025599	6.04	
10	-5.00	-0.	72.11	4565.	414.	42.	-3410.	10090.	704.	552.0	675.0	100.0	
10	4.51	0.2131	154.75	0.4006	-0.0303	0.0603	-0.0270	0.0503	0.0035	0.0036652	0.0036052	0.5025	
	0.0011	6.67	0.3060	0.037152	0.002920	0.000045	-0.002506	0.003743	0.000261	0.0024353	0.0024353	0.10	
11	-5.63	-0.	52.44	6592.	265.	-11.	-6160.	12382.	149.	652.0	635.0	101.0	
10	4.42	0.2120	154.61	0.7060	-0.0554	0.0025	-0.0305	0.0011	0.0007	0.0065571	0.0065571	0.5017	
	0.0011	5.06	0.1066	0.052615	0.004137	0.000190	-0.002260	0.004500	0.000055	0.0026353	0.0026755	0.60	
12	-5.79	-0.	53.56	7623.	203.	-62.	-5214.	13063.	-30470.	893.1	675.0	101.0	
10	4.03	0.2120	154.52	0.2313	-0.0614	-0.0054	-0.0250	0.0600	-0.3116	0.0062200	0.0062200	0.5017	
	0.0010	6.11	0.3064	0.065040	0.004502	-0.000415	-0.001036	0.005073	-0.011315	0.0040600	0.0040600	0.51	

ZERO VALUES IN	ALPHA	PSI	FL+	RL+	D	FL-	RL-	CD	CQ	D	
DIAL COUNTS..	0.	0.	500.	500.	469.	501.	500.	501.	600.	50.	0.
TOTAL PHYS. UNITS..	0.	0.	56000.	46000.	15190.	3006.	0000.	9707.	0196.	5.00	

ROTOR DATA - PROGRAM F02430 - WIND TIES 09/09/64 PAGE 6

TEST 214.0 RUN 10 STATIC 3 REFERENCE INFORMATION UPDATED TO 0.0464 TIME 56.61

BAROMETRIC PRESSURE - 29.02

PT	ALPHA	BETA	Q	LIFT,U	DRAG,U	SIDE F,U	PITCH,U	YAW,U	ROLL,U	HP	OMEGA,R	TEMP	NOTES
AVG	ALFA*	ADV+TCO	V,FPS	CL	CD	CY	CM	CN	CROLL	CP	CQ	R,TIP	
	T/TW	L/D,E	Q/QM	CLS	CDO	CYS	CMY	CNZ	CRY	CPO	CQO	L/HP	
1	-5.01	-0.	51.13	5586.	410.	56.	-5644.	10165.	-1337.	557.3	665.0	76.0	
5	5.62	0.2226	150.20	0.7901	-0.0390	0.0107	-0.0203	0.0510	-0.0067	0.0017640	0.0037645	0.5046	
	0.0014	4.43	0.3626	0.020561	0.002612	0.000700	-0.002033	0.003334	-0.000491	0.0025734	0.0025734	6.20	
2	-5.03	-0.	71.67	5635.	261.	1.	-5400.	11611.	-1230.	614.2	662.0	37.0	
5	4.76	0.3225	150.10	0.6272	-0.0522	0.0041	-0.0231	0.0506	-0.0062	0.0043322	0.0043122	0.5032	
	0.0012	6.74	0.1034	0.040104	0.007630	0.000306	-0.001943	0.004300	-0.000437	0.0026594	0.0026594	0.04	
3	-5.00	-0.	71.02	3432.	371.	-70.	-6301.	11590.	-1151.	609.4	661.0	30.0	
5	2.01	0.2221	150.47	0.0766	-0.0411	-0.0052	-0.0341	0.0502	-0.0057	0.0043061	0.0043065	0.5026	
	0.0007	0.11	0.1630	0.061515	0.003037	-0.000381	-0.002500	0.000206	-0.000415	0.0023232	0.0027032	11.07	
4	-5.50	-0.	71.40	7606.	406.	44.	-5074.	6234.	-601.	404.1	665.0	30.0	
5	4.16	0.3217	150.46	0.4015	-0.0303	0.0009	-0.0215	0.0405	-0.0030	0.0013066	0.0033066	0.3047	
	0.0011	4.76	0.1016	0.029424	0.002242	0.000645	-0.001063	0.007790	-0.000221	0.0024550	0.0024550	7.17	
5	-1.36	-0.	70.30	6121.	225.	-114.	-3110.	10111.	-2006.	801.1	705.0	85.0	
5	5.32	0.2105	130.50	0.6650	-0.0620	-0.0062	-0.0143	0.0662	-0.0134	0.0041600	0.0041460	0.6600	
	0.0012	5.50	0.3499	0.040763	0.001793	-0.000505	-0.000070	0.004090	-0.000756	0.0026432	0.0026432	5.03	

ZERO VALUES IN	ALPHA	PSI	SL+	RL+	D	YL-	RL-	CY	CQ	D	
DIAL COUNTS..	0.	0.	500.	501.	500.	475.	339.	502.	699.	51.	0.
TOTAL PHYS. UNITS..	0.	0.	50000.	46012.	15200.	2052.	0110.	0205.	0196.	5.36	

TABLE IV (Cont'd)

ROTOR 0076 • PROGRAM F0249 • RING 6773 04/09/66 PAGE 10
TEST 234.0 RUN 11 STATIC 3 REFERENCE INFORMATION UPDATED TO 9.0409 TIME 56.61
BEGINNING ZERO ONLY

BAROMETRIC PRESSURE = 30.00

PT	ALPHA	BETA	Q	LIFT,U	DRAG,U	SIDE F,U	PITCH,U	YAW,U	ROLL,U	HP	OMEGA-R	TEMP	NOTES
SVG	ALFA'	RHO-100	V,031	CL	CD	CY	CM	CN	CROLL	CP	CQ	R,TIP	
	P/TO	L/D,E	V/OR	CLD	CYD	CYD	CMY	CNZ	CRY	CPD	CQD	L/HP	
1	-2.92	-0.	69.40	3036.	400.	-22.	-4720.	4977.	-705.	239.0	656.0	60.0	
10	-0.72	0.2295	316.60	0.3376	0.0040	-0.0012	-0.0392	0.0170	-0.0057	0.0019797	0.0016797	0.5520	
	-0.0003	2.62	0.3002	0.014306	-0.000100	-0.000059	-0.001159	0.001690	-0.000250	0.0017090	0.0017090	7.34	
2	-2.56	-0.	65.70	3003.	590.	-1.	-5993.	4174.	-510.	217.6	654.0	72.0	
30	-6.52	0.2277	311.90	0.3796	0.0142	0.0016	-0.0402	0.0136	-0.0042	0.0019411	0.0019411	0.5006	
	-0.0010	3.50	0.3025	0.000200	-0.000449	0.000014	-0.002201	0.001513	-0.000190	0.0017292	0.0017292	4.40	
5	-2.04	-0.	45.05	3674.	496.	-77.	-4272.	4015.	-1260.	254.6	650.0	72.0	
10	-5.50	0.2213	117.06	0.6553	0.0050	-0.0131	-0.0342	0.0309	-0.0101	0.0017073	0.0017073	0.5024	
	-0.0002	5.12	0.3023	0.029925	-0.000293	-0.059500	-0.001594	0.001765	-0.000463	0.0017592	0.0017592	16.00	
6	-2.30	-0.	90.51	5091.	615.	-135.	-5032.	4301.	-1159.	229.5	650.0	12.0	
10	-1.06	0.2213	317.77	0.9000	0.0299	-0.0230	-0.0467	0.0145	-0.0091	0.0015929	0.0015926	0.5015	
	-0.0007	6.55	0.3023	0.041470	-0.001350	-0.001702	-0.002133	0.001573	-0.000427	0.0017070	0.0017030	21.77	
5	-2.91	-0.	66.52	1736.	557.	-31.	-3059.	4175.	-330.	217.0	650.0	73.0	
10	-3.02	0.2271	137.01	0.2996	0.0150	-0.0020	-0.0109	0.0135	-0.0027	0.0015317	0.0015315	0.5010	
	-0.0012	2.40	0.3022	0.013601	-0.000721	-0.000129	-0.001411	0.001527	-0.000123	0.0017271	0.0017271	7.95	
8	-2.93	-0.	66.73	3000.	604.	-39.	-4105.	3901.	-232.	203.9	690.0	74.0	
10	-4.05	0.2290	111.73	0.2939	0.0240	-0.0077	-0.0352	0.0314	-0.0019	0.0014231	0.0014231	0.5030	
	-0.0015	7.37	0.7930	0.037229	-0.001123	-0.000160	-0.001597	0.001421	-0.000005	0.0017402	0.0017402	7.74	
7	-2.45	-0.	44.02	1703.	925.	-35.	-4941.	3697.	-200.	197.4	600.0	34.0	
10	-5.55	0.2200	117.77	0.2992	0.0200	-0.0076	-0.0373	0.0297	-0.0023	0.0017502	0.0013502	0.5030	
	-0.0022	2.93	0.3032	0.033944	-0.001290	-0.000164	-0.001691	0.001767	-0.000102	0.0017100	0.0017100	0.24	

ZERO VALUES IN ALPHA PSI FL+ M+ Q FL- ML- CF CQ Q
DIAL COUNTS.. 0. 0. 901. 500. 499. 565. 501. 501. 499. 49. 0.
TOTAL PHYS. UNITS.. 0. 0. 14012. 40000. 15190. 5004. 8004. 0202. 0150. 2.06

ROTOR 0076 • PROGRAM F0249 • RING 9781 09/09/66 PAGE 12
TEST 234.0 RUN 15 STATIC 3 REFERENCE INFORMATION UPDATED TO 0.6464 TIME 56.61
BEGINNING ZERO ONLY

BAROMETRIC PRESSURE = 29.00

PT	ALPHA	BETA	Q	LIFT,U	DRAG,U	SIDE F,U	PITCH,U	YAW,U	ROLL,U	HP	OMEGA-R	TEMP	NOTES
SVG	ALFA'	RHO-100	V,031	CL	CD	CY	CM	CN	CROLL	CP	CQ	R,TIP	
	P/TO	L/D,E	V/OR	CLD	CYD	CYD	CMY	CNZ	CRY	CPD	CQD	L/HP	
1	-6.56	-0.	76.00	1003.	927.	5.	-6361.	5171.	-15.	203.1	660.0	85.0	
10	-4.02	0.2131	157.59	0.1703	0.0125	0.0040	-0.0190	0.0252	-0.0001	0.0019026	0.0015026	0.5020	
	-0.0009	2.65	0.3976	0.014094	-0.000991	0.000120	-0.002159	0.001990	-0.000007	0.0021505	0.0021505	5.04	
2	-6.06	-0.	76.63	1494.	904.	6.	-9033.	4994.	609.	243.0	607.0	95.0	
10	-6.65	0.2147	158.90	0.1600	0.0107	0.0042	-0.0325	0.0220	0.0029	0.0017417	0.0017417	0.5100	
	-0.0011	2.90	0.4311	0.012007	-0.001500	0.000110	-0.002912	0.001760	0.000225	0.0023205	0.0023205	6.09	
5	-6.99	-0.	77.26	3016.	1010.	-11.	-9012.	4530.	412.	236.0	945.0	98.0	
10	-9.92	0.2131	159.11	0.1721	0.0209	0.0019	-0.0317	0.0211	0.0010	0.0016060	0.0016060	0.5701	
	-0.0010	2.46	0.4021	0.013912	-0.001900	0.000150	-0.002505	0.001709	0.000155	0.0023472	0.0023472	6.70	
4	-4.92	-0.	31.05	3510.	993.	-84.	-4427.	5145.	-670.	273.1	660.0	89.0	
10	-2.65	0.2132	159.29	0.3555	0.0195	-0.0760	-0.0500	0.0240	-0.0022	0.0019493	0.0019403	0.5775	
	-0.0009	7.05	0.4019	0.020704	-0.001130	-0.000532	-0.002424	0.001941	-0.000180	0.0024095	0.0024095	12.11	
5	-4.89	-0.	77.03	4399.	990.	-141.	-7009.	5204.	-686.	201.5	669.0	99.0	
10	-2.19	0.2132	159.27	0.4497	0.0172	-0.0117	-0.0331	0.0241	-0.0032	0.0020001	0.0020001	0.5770	
	-0.0005	5.95	0.4010	0.030905	-0.001301	-0.000942	-0.002676	0.001963	-0.000250	0.0024462	0.0024462	14.06	
6	-4.00	-0.	77.22	5025.	904.	-215.	8100.	5503.	-1386.	209.0	675.0	100.9	
10	-1.96	0.2120	150.61	0.6025	0.0206	-0.0151	0.0370	0.0257	-0.0065	0.0020061	0.0020003	0.5025	
	-0.0004	7.31	0.3093	0.047900	-0.001641	-0.001595	-0.003007	0.002043	-0.000514	0.0025250	0.0025250	10.79	
7	-5.50	-0.	73.29	563.	1050.	12.	-5001.	3971.	610.	201.6	673.0	101.0	
10	-17.66	0.2124	159.03	0.0705	0.0250	0.0040	-0.0270	0.0195	0.0020	0.0014003	0.0014003	0.5000	
	-0.0041	1.16	0.4005	0.000303	-0.002001	0.000706	-0.002170	0.001404	0.000220	0.0022612	0.0022612	1.55	
8	-4.90	-0.	90.19	4609.	917.	-135.	-8527.	9232.	-1096.	530.0	720.0	102.0	
10	0.37	0.2103	173.36	0.4000	-0.0026	-0.0009	-0.0140	0.0360	-0.0070	0.0030170	0.0030170	0.6295	
	0.0001	4.76	0.5015	0.032795	0.006212	-0.000717	-0.002749	0.002976	-0.000611	0.0020755	0.0020155	0.21	

ZERO VALUES IN ALPHA PSI FL+ ML+ Q FL- ML- CF CQ Q
DIAL COUNTS.. -10. 0. 612. 529. 500. 516. 405. 502. 499. 30.
TOTAL PHYS. UNITS.. -5.00 0. 55904. 96352. 15200. 5004. 7910. 9205. 9190. 3.00

TABLE IV (Cont'd)

TABLE IV (Cont'd)

Explaination of Wind Tunnel Data Symbols		
Symbol	Meaning	Definition (in terms of these symbols where possible)
ALFA'	Resultant rotor force orientation (degrees)	$\tan^{-1}\left(\frac{\text{Drag-Drag}_{tare}}{\text{Lift-Lift}_{tare}}\right)$
ALPHA	Mast angle of rotor (degrees)	positive for mast tilted aft
AVG	Data are an average of 5 or 10 points, whichever is printed in this location	-
BETA	Undefined	-
CD	Rotor horizontal force coefficient, corrected	$\text{DRAG,U}_{corr}/Q\ \sigma\ A$
CL	Rotor lift coefficient, corrected	$\text{LIFT,U}_{corr}/Q\ \sigma\ A$
CLR	Rotor lift coefficient (nondimensionalized by tip speed)	$\text{CL} \cdot (\text{V/OR})^2/2$
CM	Rotor pitching moment coefficient, corrected	$\text{PITCH,U}_{corr}/Qc\ \sigma\ A$
CMX	Rotor rolling moment coefficient (nondim. by tip speed)	$\text{CROLL}\cdot(\text{V/OR})^2/2$
CMY	Rotor pitching moment coefficient (nondim. by tip speed)	$\text{CM}\cdot(\text{V/OR})^2/2$
CMZ	Rotor yawing moment coefficient (nondim. by tip speed)	$\text{CN}\cdot(\text{V/OR})^2/2$
CN	Rotor yawing moment coefficient, corrected	$\text{YAW,U}_{corr}/Qc\ \sigma\ A$
CP	Rotor power coefficient	$\frac{\text{HP}\cdot 55000}{(\text{RHO}*100)\text{A}(\text{OMEGA}*\text{R})^3}$

TABLE IV (Cont'd)

Symbol	Meaning	Definition (in terms of these symbols where possible)
CPO	Rotor profile power coefficient	See page 7, $\left.\frac{C_{P_o}}{\sigma}\right\|_1$
CQ	Same as CP	-
CQO	Same as CPO	-
CROLL	Rotor rolling moment coefficient, corrected	$ROLL,U_{corr}/Qc\,\sigma\,A$
CXR	Rotor drag coefficient (nondim. by tip speed)	$CD\cdot(V/OR)^2/2$
CY	Rotor yawing moment coefficient, corrected	$YAW,U_{corr}/Qc\,\sigma\,A$
CYR	Rotor yawing moment coefficient (nondim. by tip speed)	$CY\cdot(V/OR)^2/2$
DRAG,U	Rotor horizontal force, uncorrected	pounds, positive aft
F/TV	Propulsive force parameter	CXR·Q/CLR
HP	Rotor horsepower measured by balance frame	-
L/D,E	Efficiency parameter	$CLR/(\frac{.945(CP)}{V/OR} - CXR)$
L/HP	Efficiency parameter	CLR·550/CP·OMEGA*R
LIFT,U	Rotor vertical force, uncorrected	pounds, positive up
M,TIP	Rotational tip Mach number	$\frac{OMEGA*R}{\text{Speed of sound}}$
OMEGA*R	Rotor tip speed	feet/second
PITCH,U	Rotor pitching moment, uncorrected	ft-lbs, positive nose up

TABLE IV (Cont'd)

Symbol	Meaning	Definition (in terms of these symbols where possible)
PT	Datum point number in a given run	-
Q	Dynamic pressure (lb/ft^2)	$.01426(RHO*100)(V,KTS)^2$
RHC*100	Air density *100 ($slugs/ft^3$)	-
ROLL,U	Rotor rolling moment, uncorrected	ft-lbs, positive for advancing blade down
SIDE,U	Rotor side force, uncorrected	lbs, positive to right (looking upwind)
TEMP	Tunnel temperature (°F)	-
V/OR	Rotor tip speed ratio	$\frac{1.6878(V,KTS)}{OMEGA*R}$
V,KTS	True airspeed (knots)	-
YAW,U	Rotor yawing moment, uncorrected	ft-lbs, positive nose right (looking upwind)

TABLE V

CONTROL POSITION DATA

Run and Point number relate to Table IV data.						
Run	Point	Grip Collective (θ_0-1.45°) + up deg	Longitudinal Cyclic + fwd deg	Lateral Cyclic + right deg	Oscill. Record Number	Remarks
6	1	10.5	3.0	0.0	123	
	2	10.5	1.0		124	
	3	10.5	-1.0		125	
	4	11.5			126	
	5	12.5			127	
	6	13.5			128	
	7	9.5	1.0		129	Chg zero osc. 2
	8	9.5	3.0		130	
	9	9.5	5.0		131	
	10	8.5	3.0		132	Chg zero osc. 1
	11	10.5			133	
	12	11.5			134	
	13	12.5			135	
	14	12.7			137	
	15	13.3			138	
	16	13.5	4.0		141	
	17	14.5	7.0		142	
	18	15.5			143	
	19	17.0			144	
	20	13.5			145	Chg zero osc. 1
	21	13.75			146	
7	1	10.5	3.0	0.0	175	Beam 95 ampl. out
	2	9.5			176	
	3	11.5			177	
	4	12.5			178	Chord flexure 2 out
	5	13.5			179	
	6	14.0			180	
	7	10.5	4.0		181	
	8	10.5	2.0		182	
	9	10.5	3.0		183	
	10	9.5			185	
	11	11.5			186	
	12	12.0			187	
	13	12.5			188	
	14	13.0			189	

TABLE V (Cont'd)

Run	Point	Grip Collective (θ_0-1.45°) + up deg	Longitudinal Cyclic + fwd deg	Lateral Cyclic + right deg	Oscill. Record Number	Remarks
7	15	10.5	4.0	0.0	190	
	16	10.5	2.0		191	
	17	12.8	4.5		196	
	18	11.5			197	
	19	13.8			198	
	20	15.0			199	
	21	12.8	6.5		200	
	22	12.8	2.5		201	
	23	11.75	4.5		202	
	24	10.8			203	
	25	12.8			204	
	26	13.8			205	
	27	14.8			206	
	28	11.75	6.5		207	
	29	11.75	2.5		208	
	30	11.8	4.5		209	
	31	10.5			211	
	32	12.8			212	
	33	13.5			215	
	34	11.8	6.5		216	
	35	11.8	2.5		217	
8	1	15.5	7.0	0.0	222	Slight foul for all of Run 8
	2	14.5			223	
	3	16.5			225	
	4	16.5		1.5	226	
	5	17.5			227	
	6	15.5			228	
	7	15.5	9.0		229	
	8	15.5	5.0		230	
	9	15.0	7.0		231	
	10	14.5			232	
	11	15.5			233	
	12	16.0			235	
9	1	14.5	7.0	1.5	255	
	2	15.0			256	
	3	15.5			257	
	4	16.0			258	
	5	16.5			259	
10	1	15.0	9.0	1.5	268	
	2	15.0	7.0		269	
	3	15.0	5.0		270	

TABLE V (Cont'd)

Run	Point	Grip Collective (Θ_0-1.45°) + up deg	Longitudinal Cyclic + fwd deg	Lateral Cyclic + right deg	Oscill. Record Number	Remarks
10	4	14.0	7.0	1.5	271	
	5	14.2	7.0		272	Rezero Chan. 6 Oscill. 2
11	1	8.9	4.5	0.0	285	
	2	8.5	4.5		286	
	3	8.9	2.5		287	
	4	8.9	0.5		288	
	5	7.5	2.5		289	
	6	7.1	0.5		290	
	7	6.7	-0.5		291	Some zeros shifted by 100 K
12	1	10.8	4.5	0.0	297	Flapping and mast torque out
	2	11.0	6.5		298	
	3	10.2			299	
	4	9.6			300	
	5	9.2			301	
	6	8.8			303	Rezero Chan. 2 Oscill. 2
	7	8.8	4.5		304	
	8	8.3	4.5		305	
	9	7.9	2.5		306	
	10	7.4	2.5		307	
	11	12.4	6.5		308	
	12	14.3	10.0		309	
	13	13.3	10.0		310	
13	1	10.5	4.7	0.0	317	
	2	9.2	2.7		318	
	3	8.3	0.7		319	Rezero Chan. 2 Oscill. 2
	4	9.4			320	
	5	9.8			321	
	6	10.6			322	
	7	7.8			323	
	8	11.9	5.4		325	Actuator failure

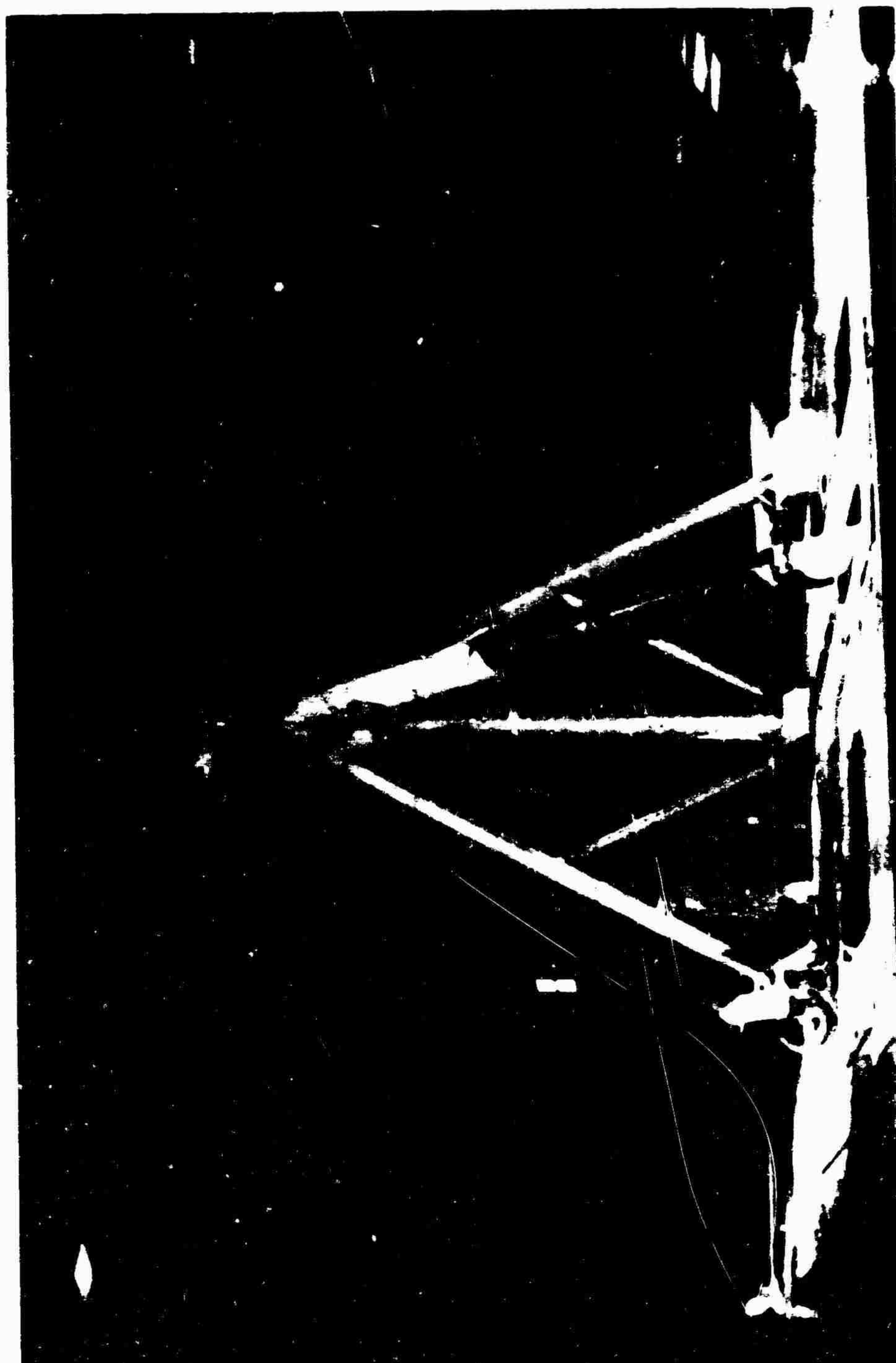

Figure 1. Rotor Test Installation.

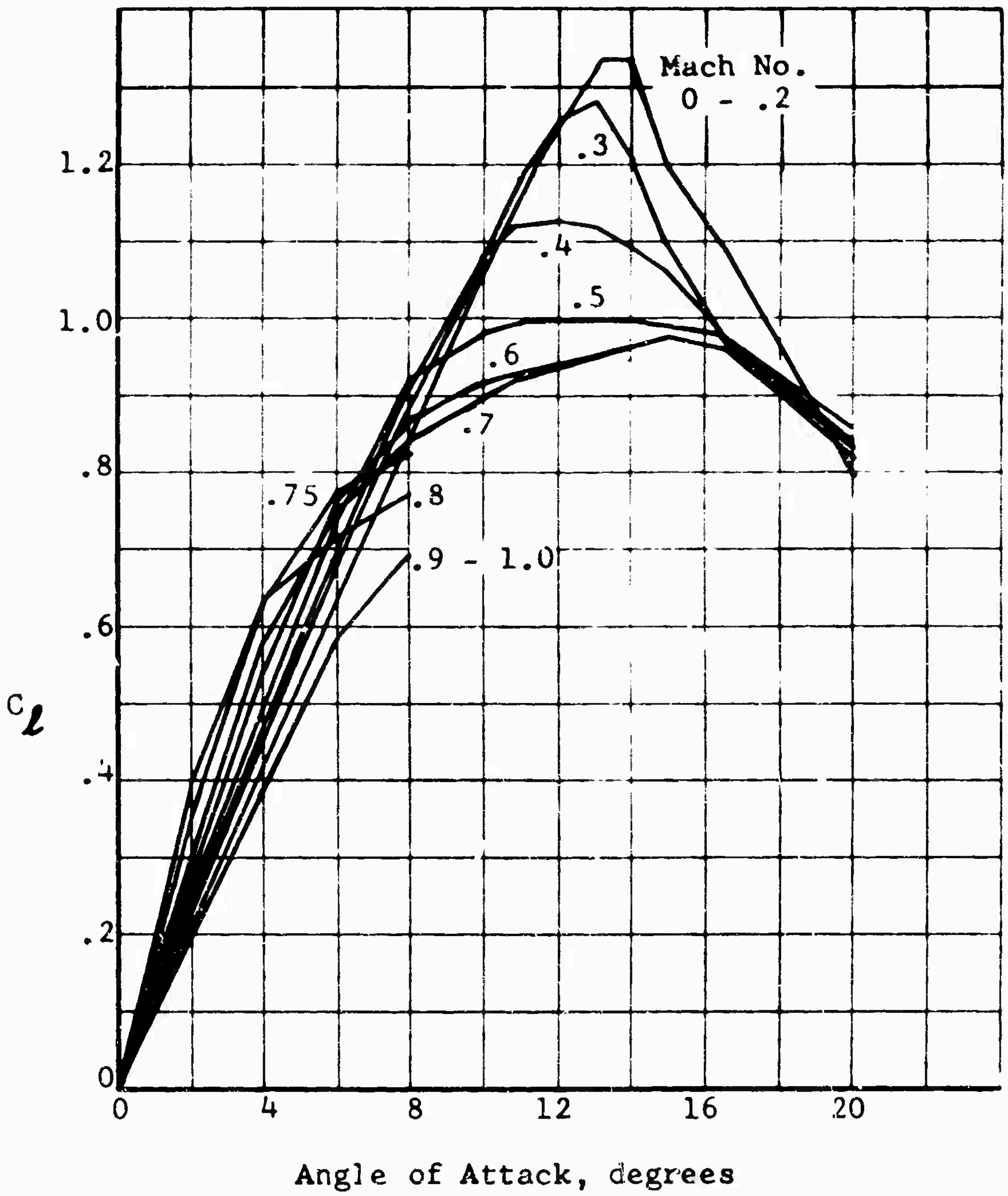

Figure 2. Airfoil Lift Characteristics.

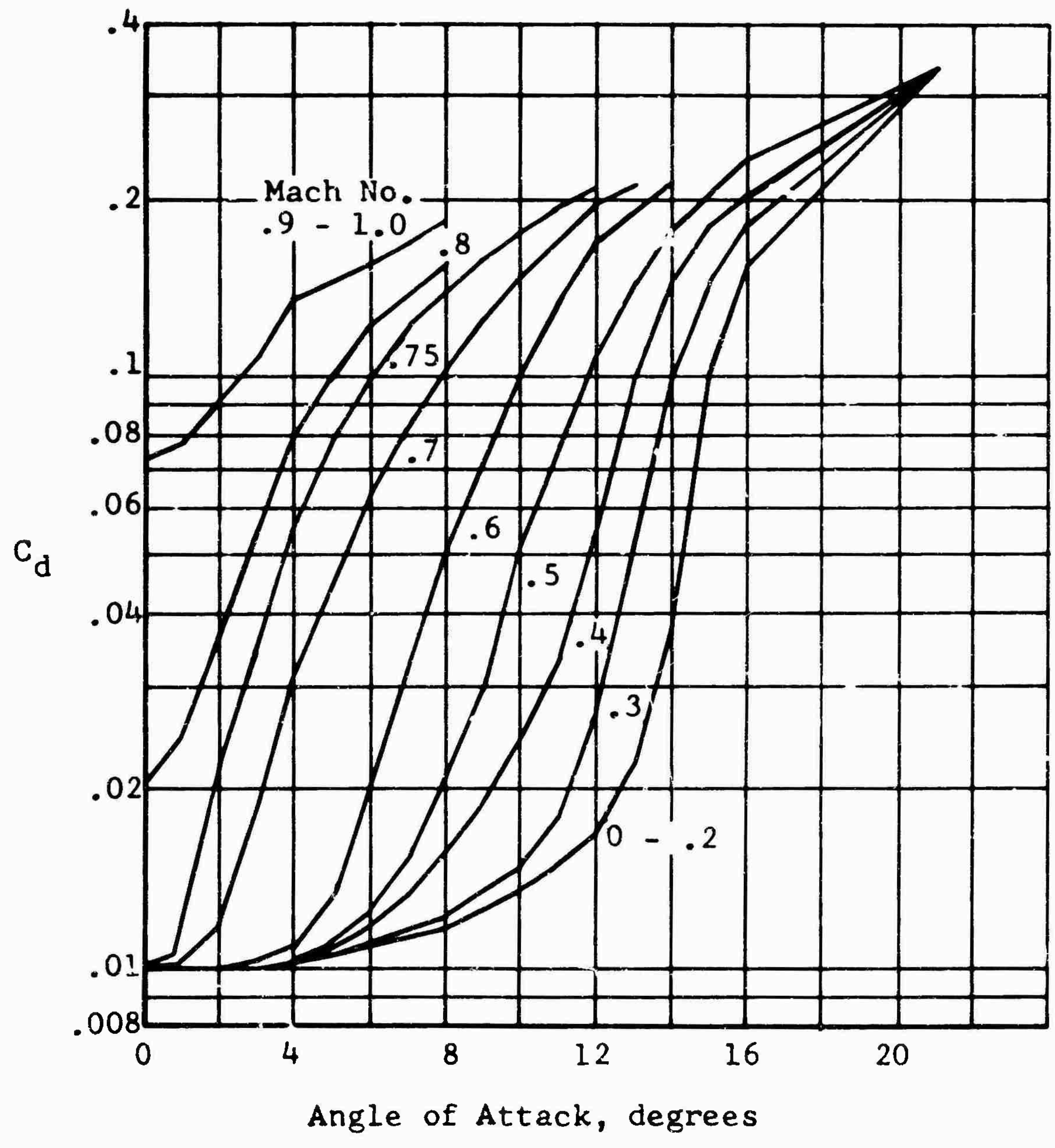

Figure 3. Airfoil Drag Characteristics.

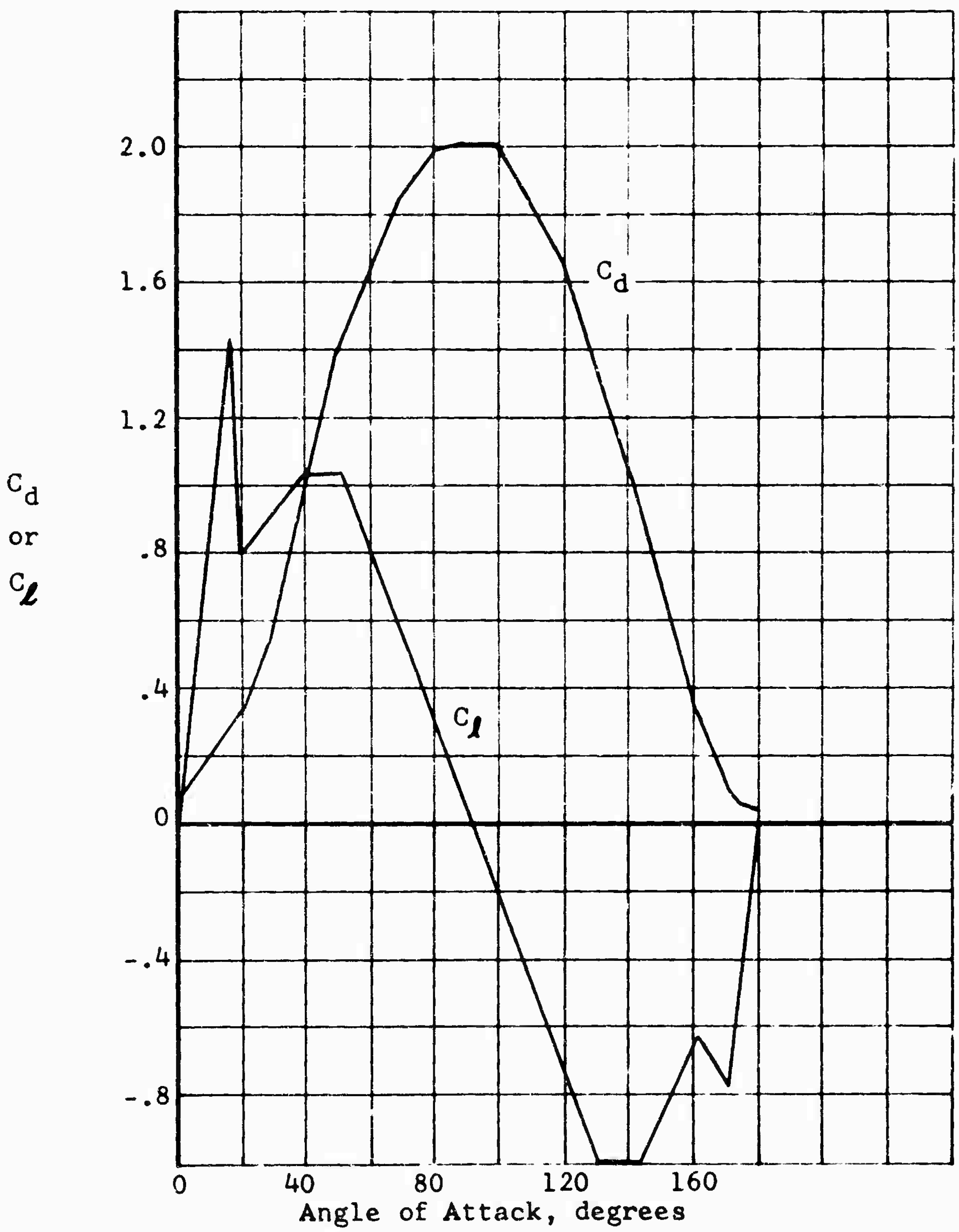

Figure 4. Stalled Airfoil Lift and Drag Characteristics.

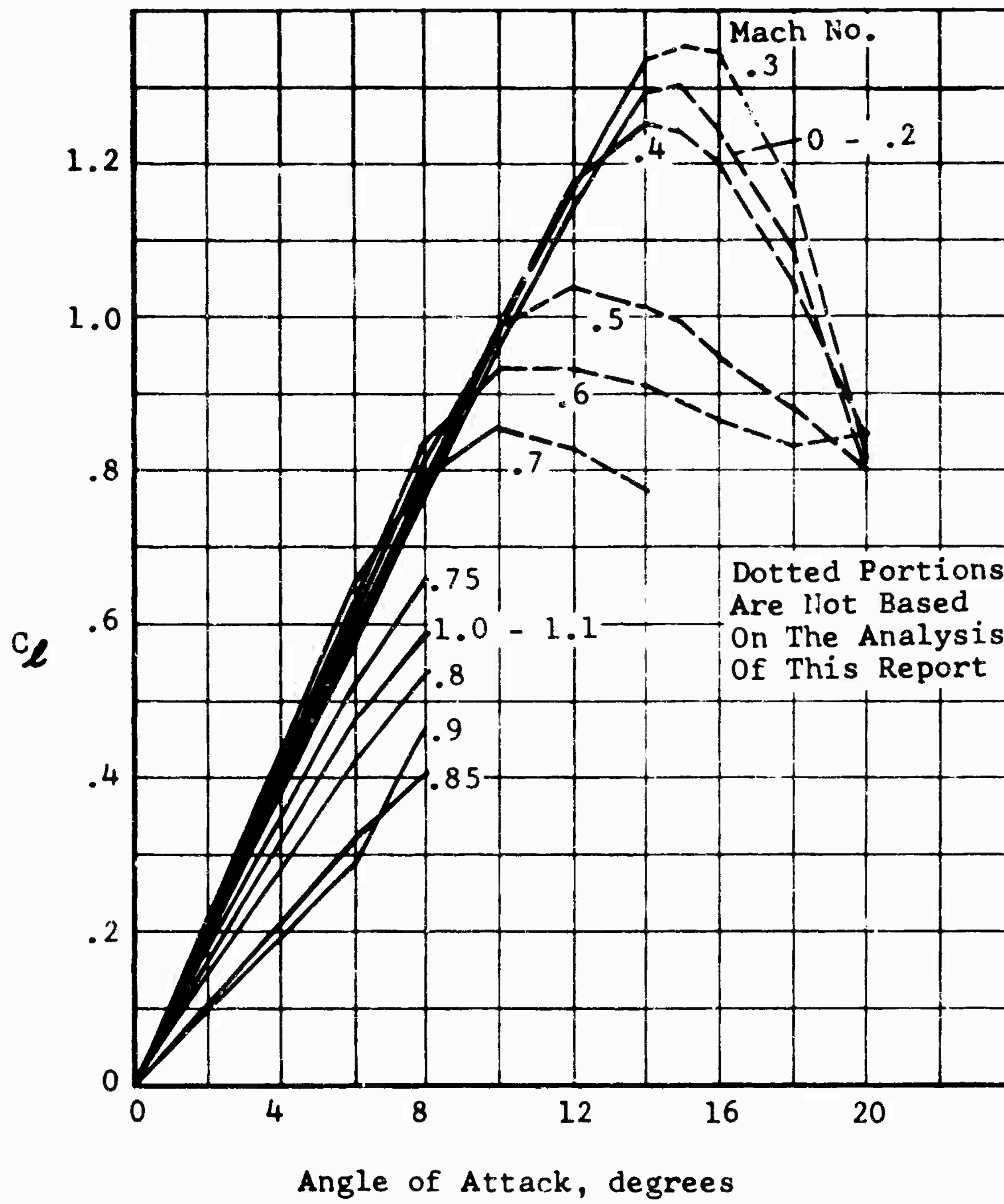

Figure 5. Synthesized Airfoil Lift Characteristics.

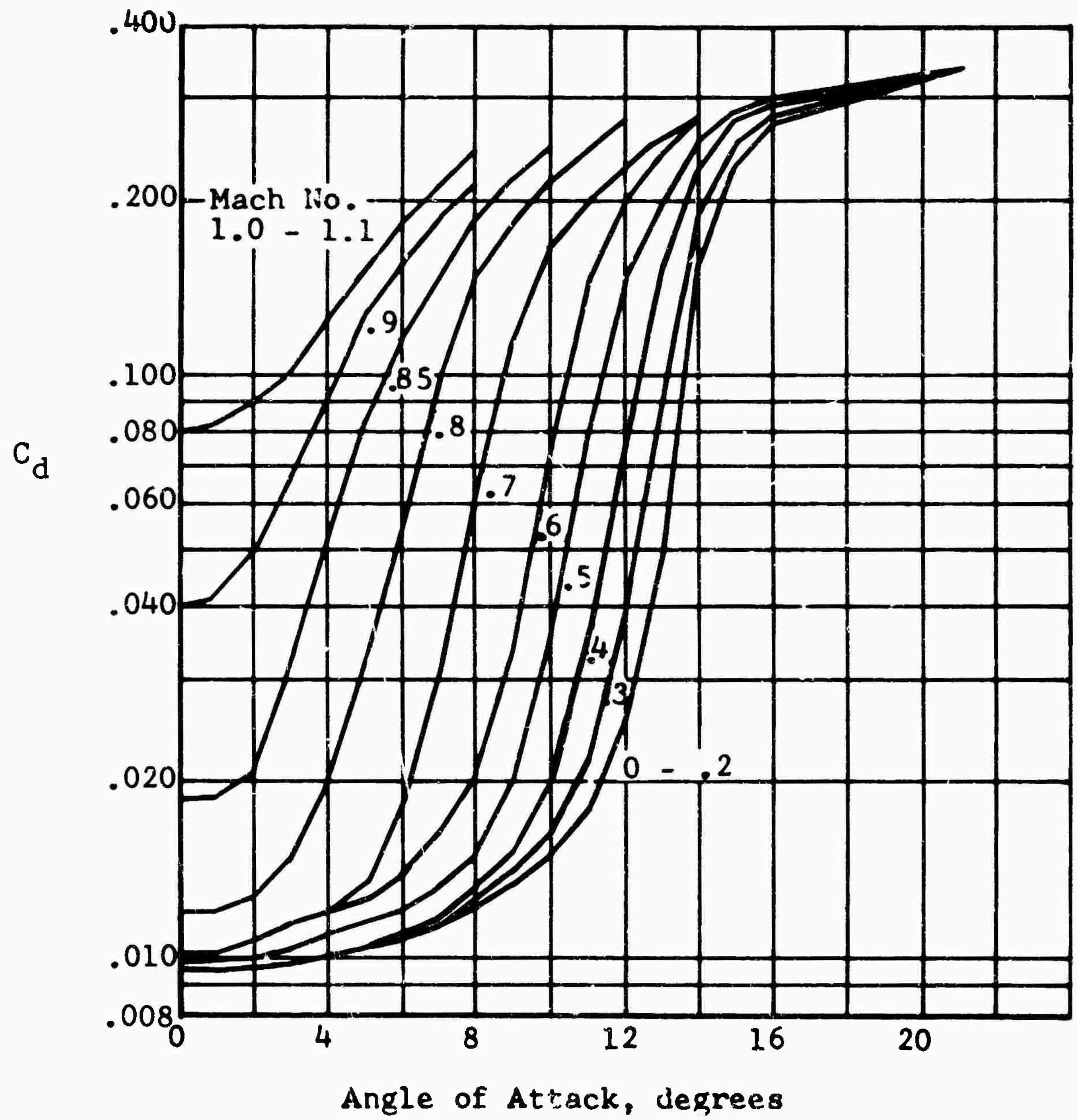

Figure 6. Synthesized Airfoil Drag Characteristics.

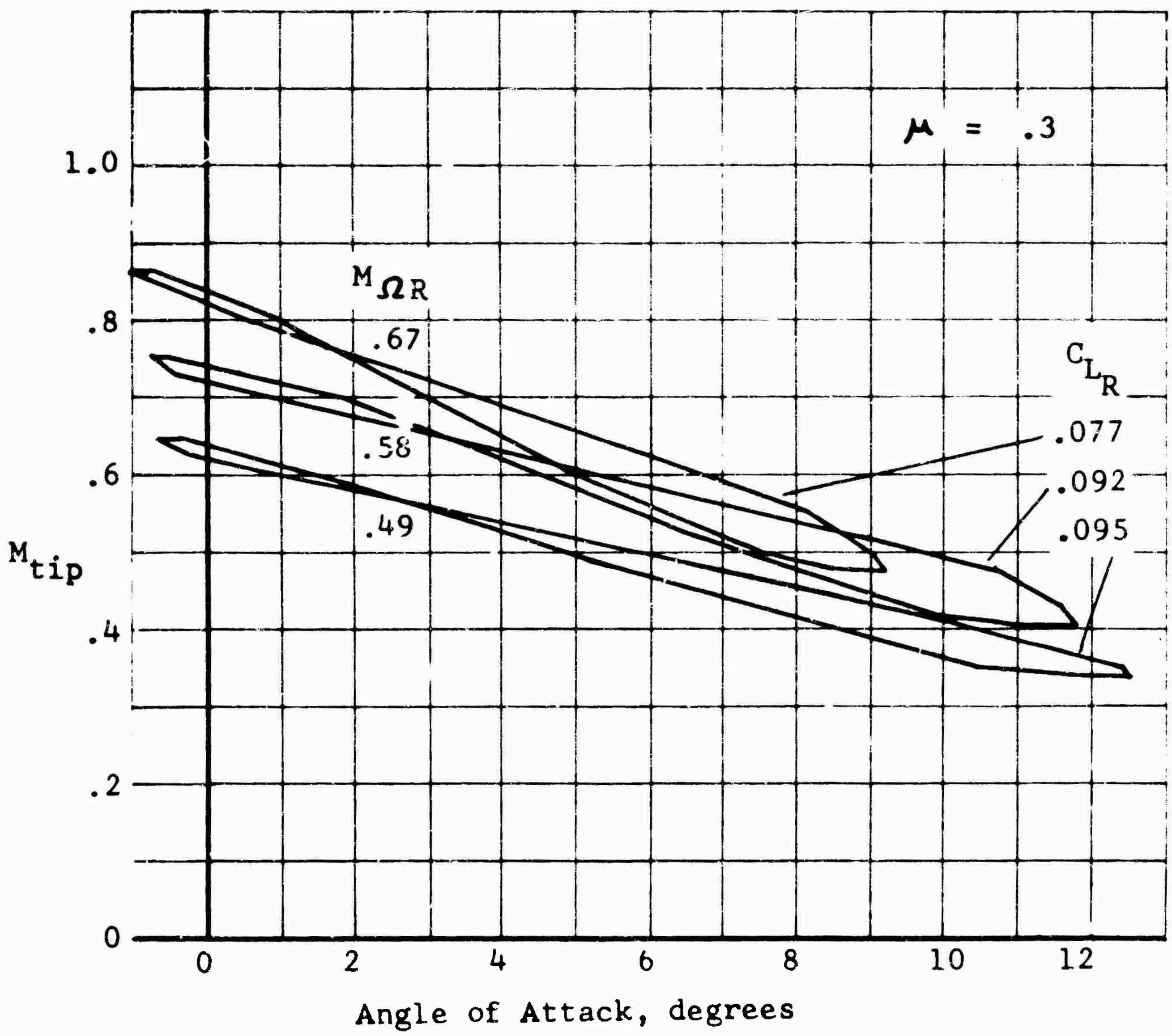

Figure 7. Mach Number - Angle-of-Attack Contours.

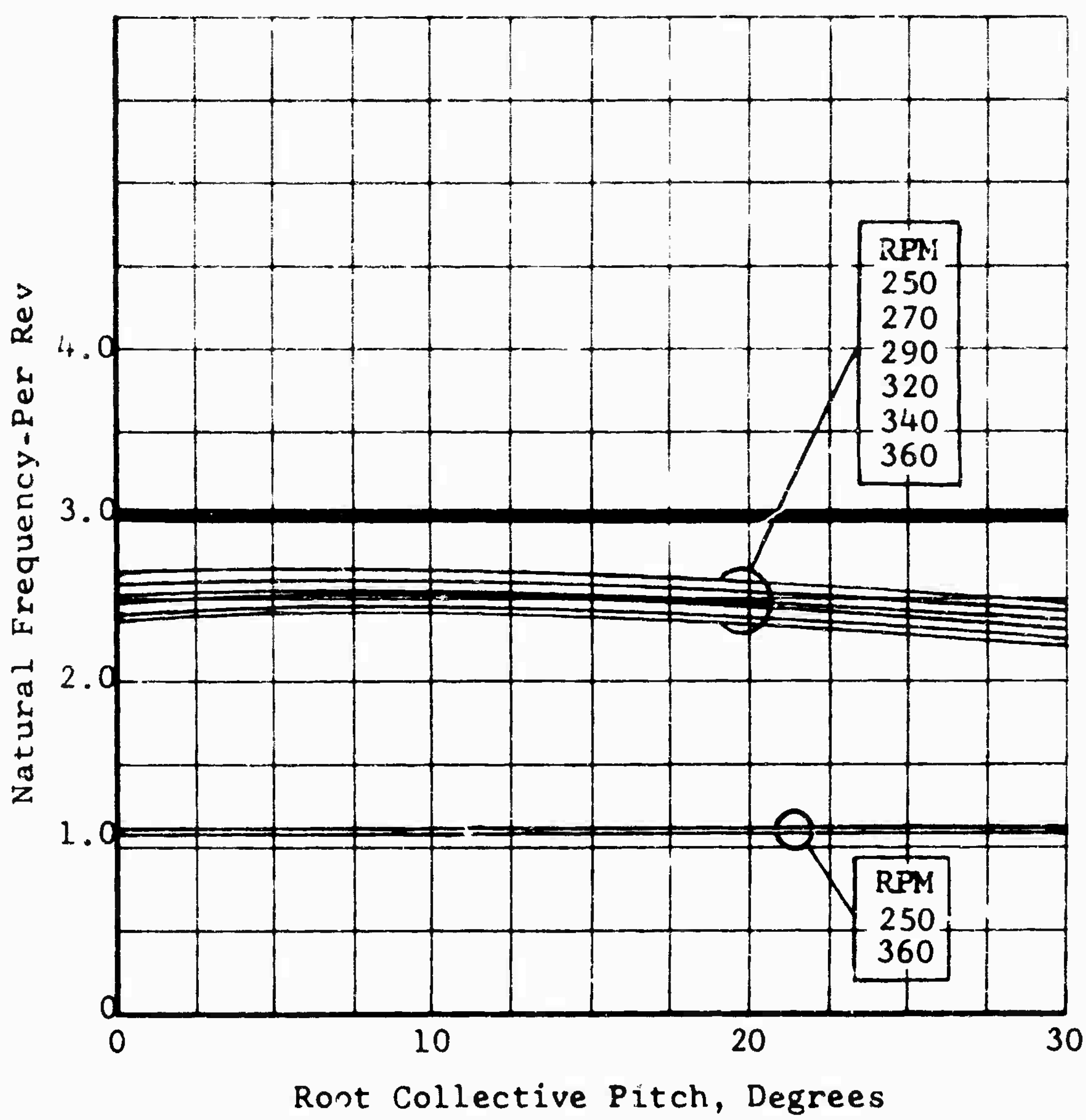

Figure 8. Calculated Blade Natural Frequencies - Collective Mode.

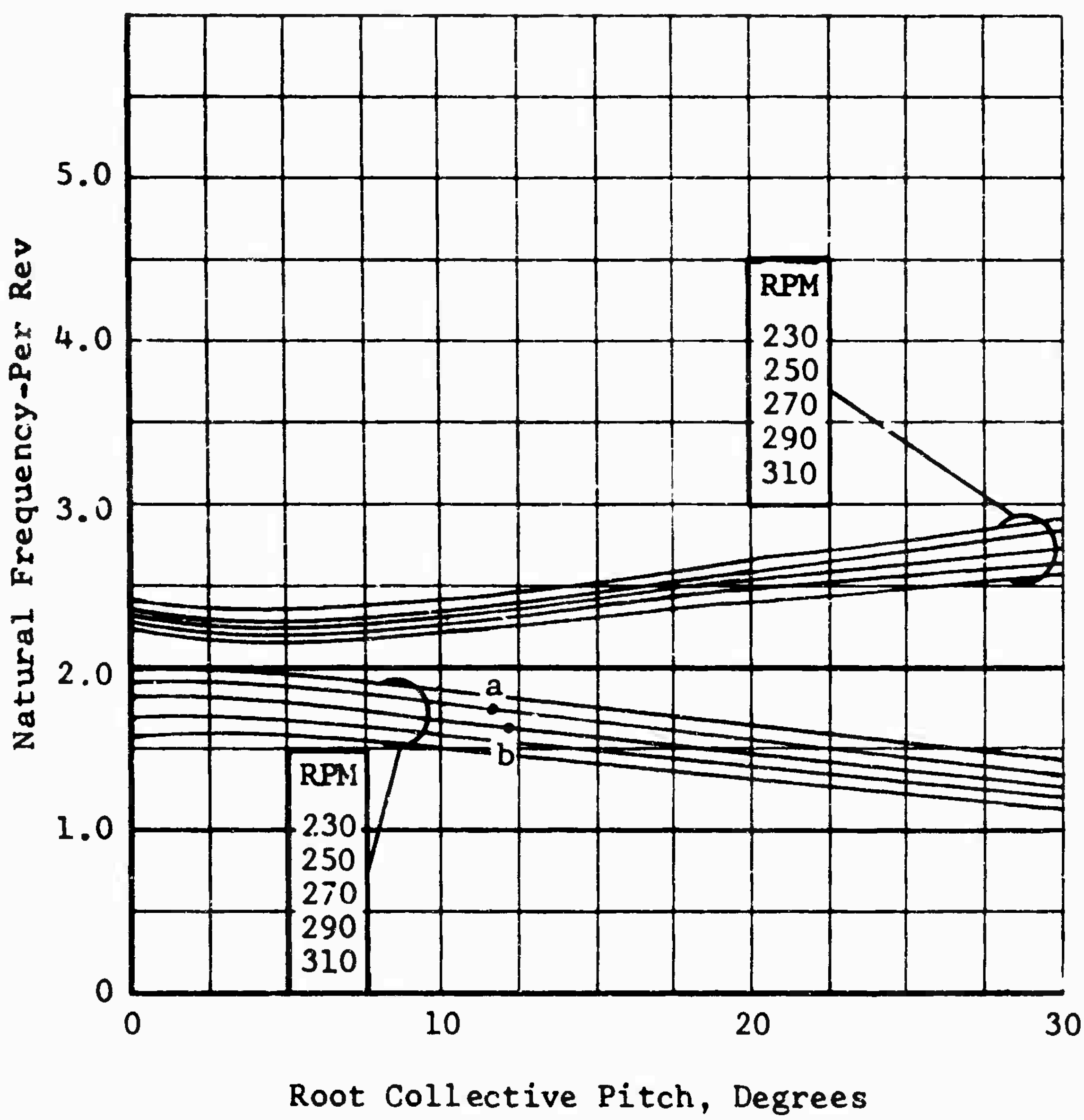

Figure 9. Calculated Blade Natural Frequencies - Cyclic Mode.

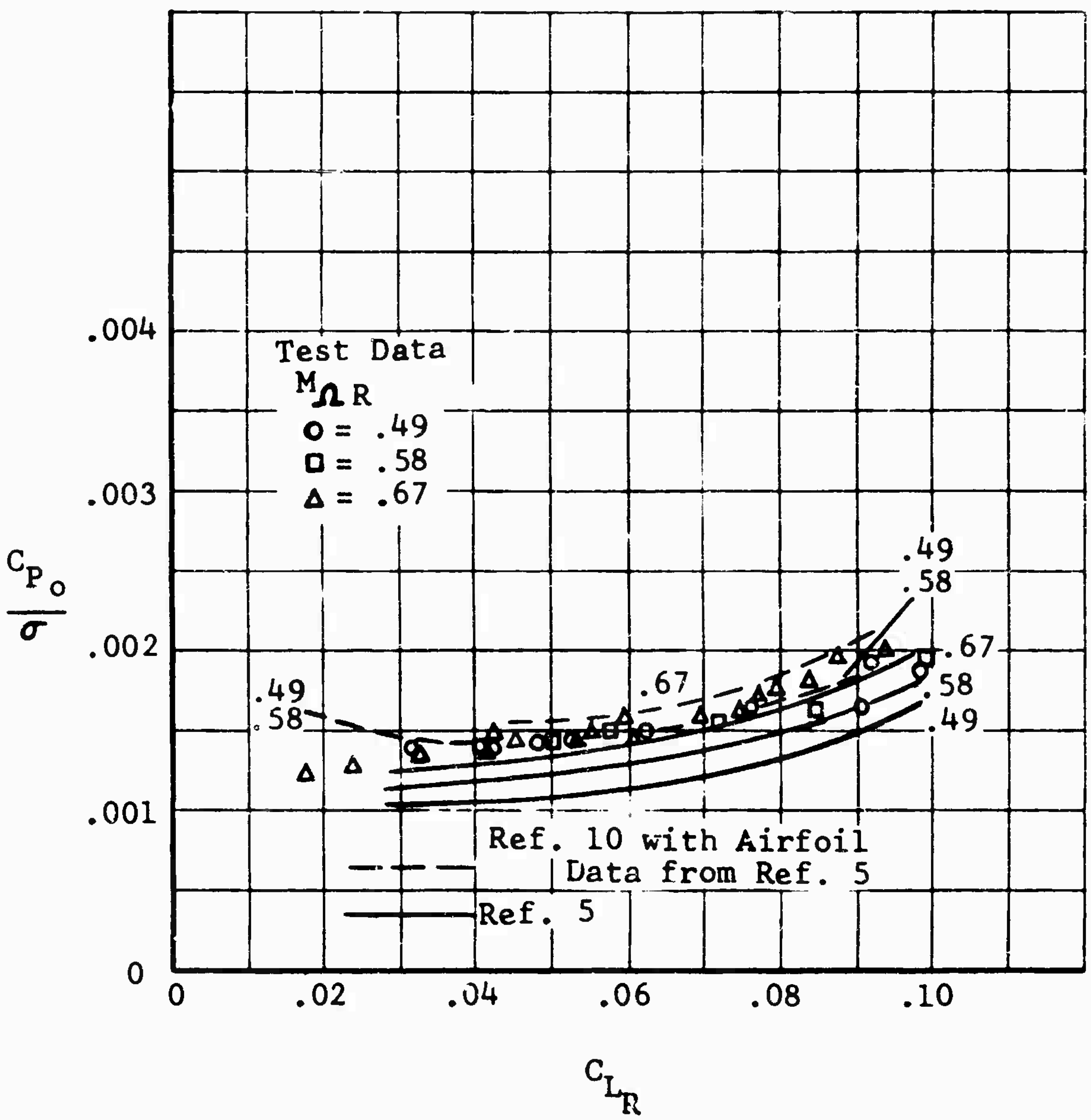

Figure 10. Profile Power Variation With Lift Coefficient, μ = .2.

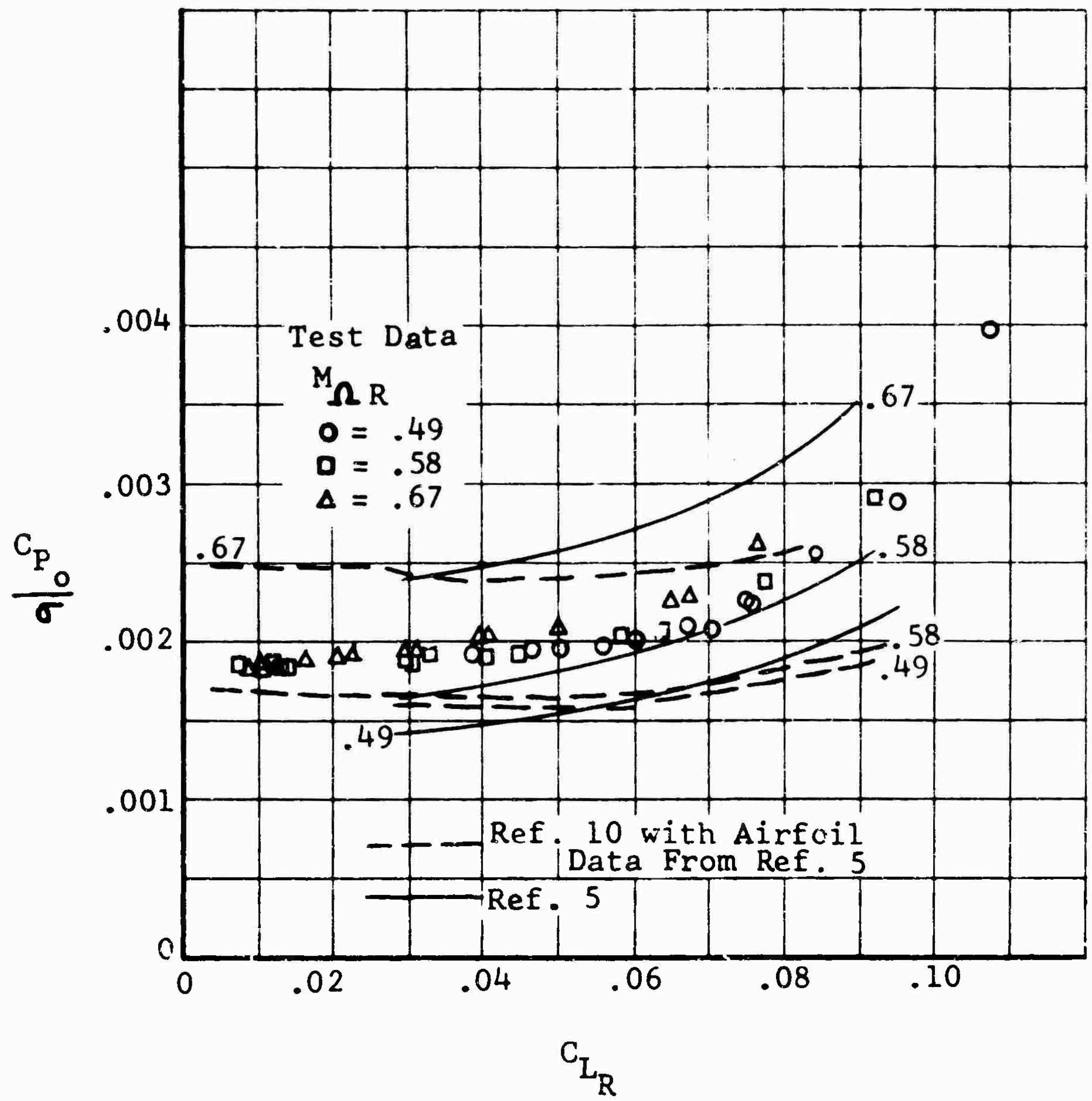

Figure 11. Profile Power Variation With Lift Coefficient, μ = .3.

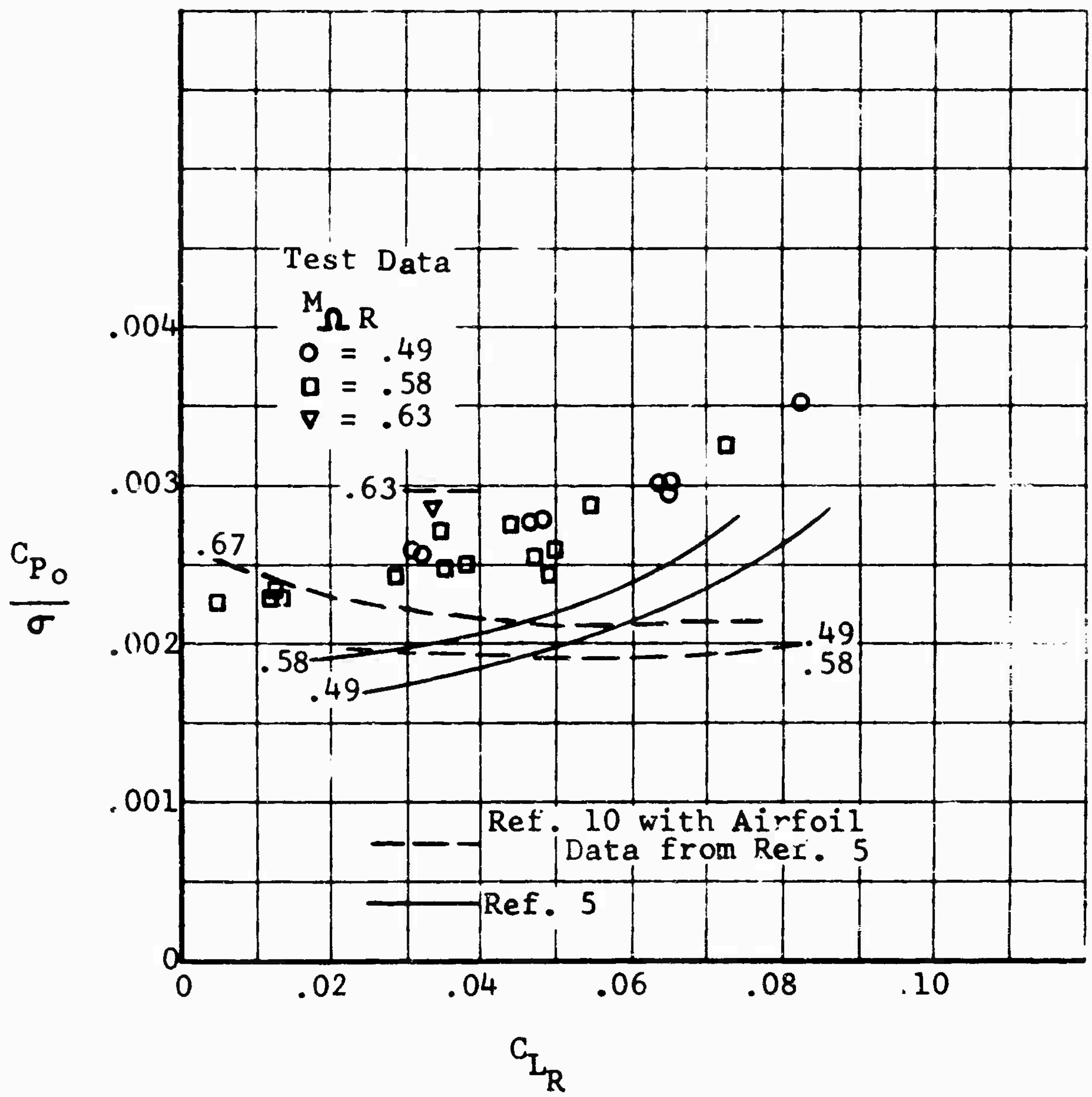

Figure 12. Profile Power Variation With Lift Coefficient, μ = .4.

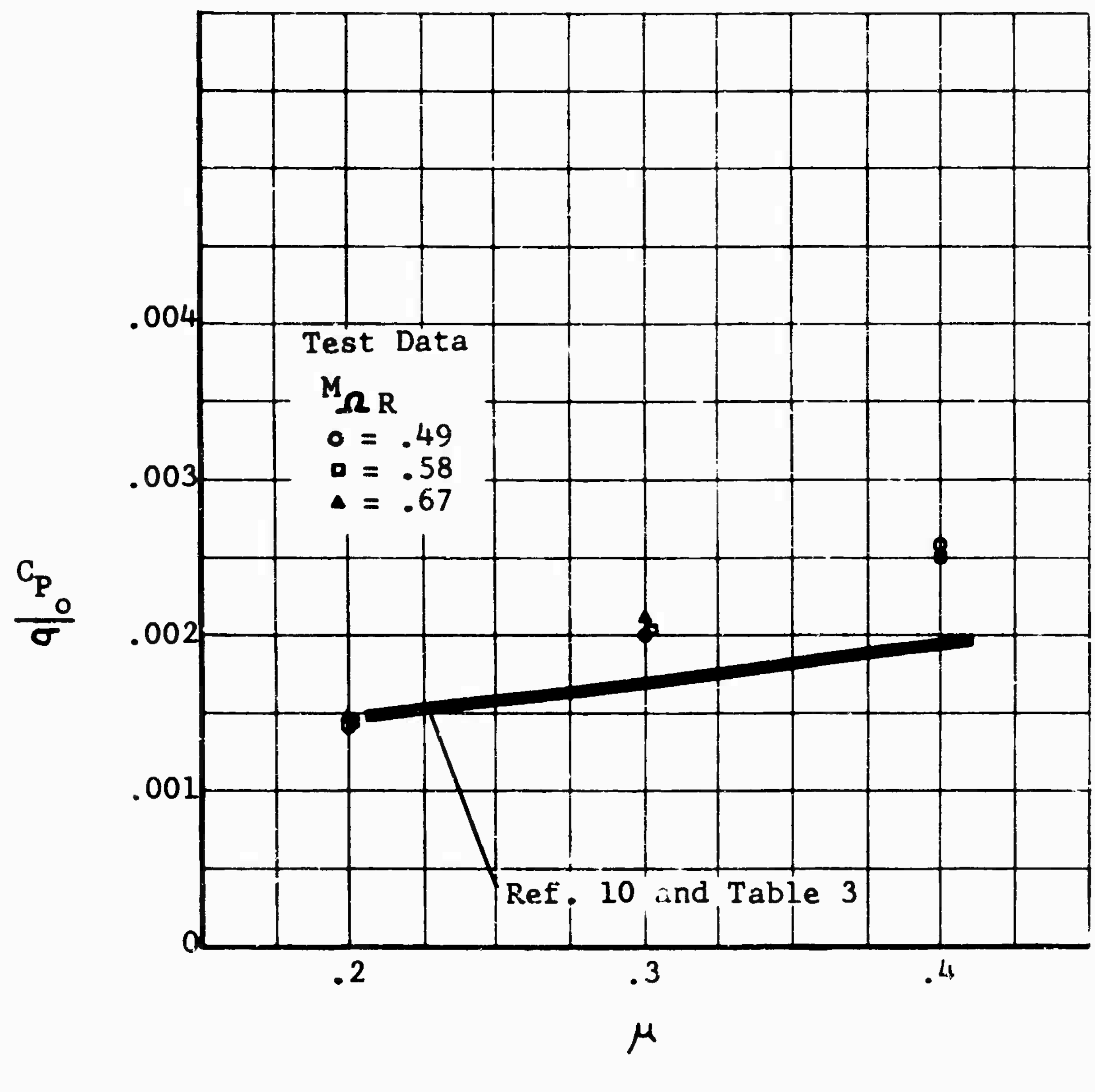

Figure 13. Profile Power Variation With Advance Ratio, C_{L_R} = .05.

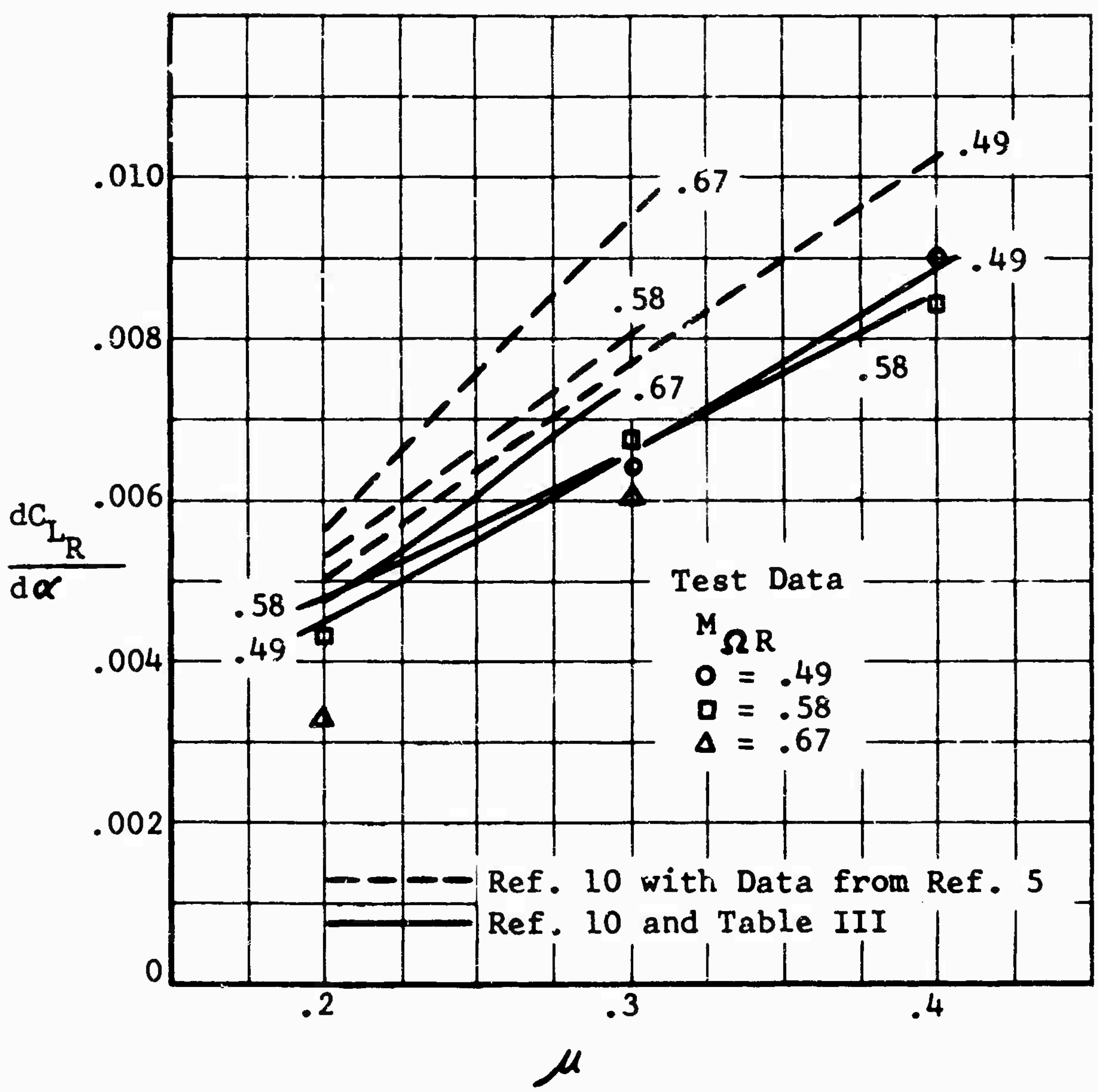

Figure 14. $d(C_{L_R})/d\alpha$ Variation With Advance Ratio, C_{L_R} = .05.

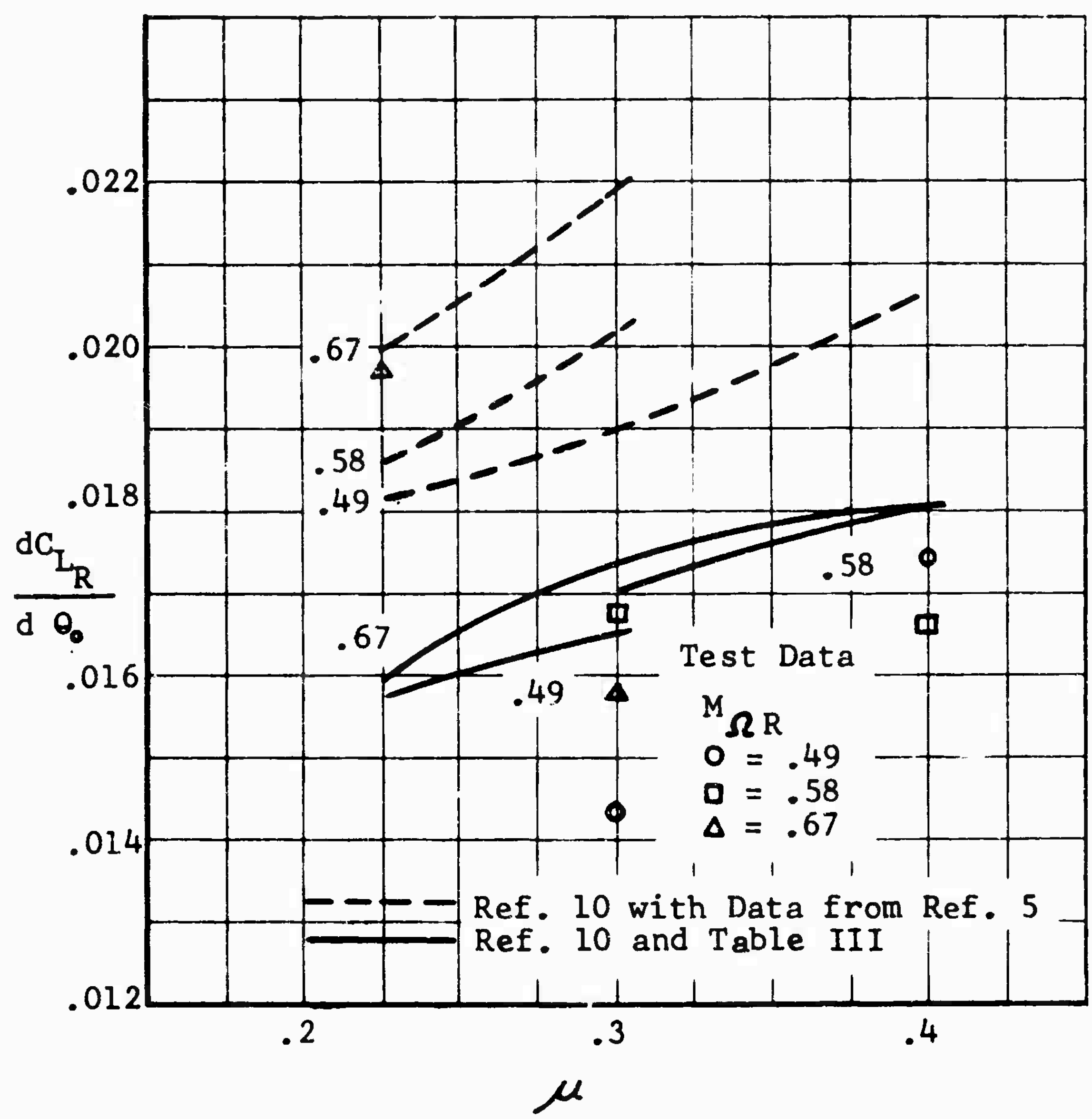

Figure 15. $d(C_{L_R})/d\theta_o$ Variation With Advance Ratio, C_{L_R} = .05.

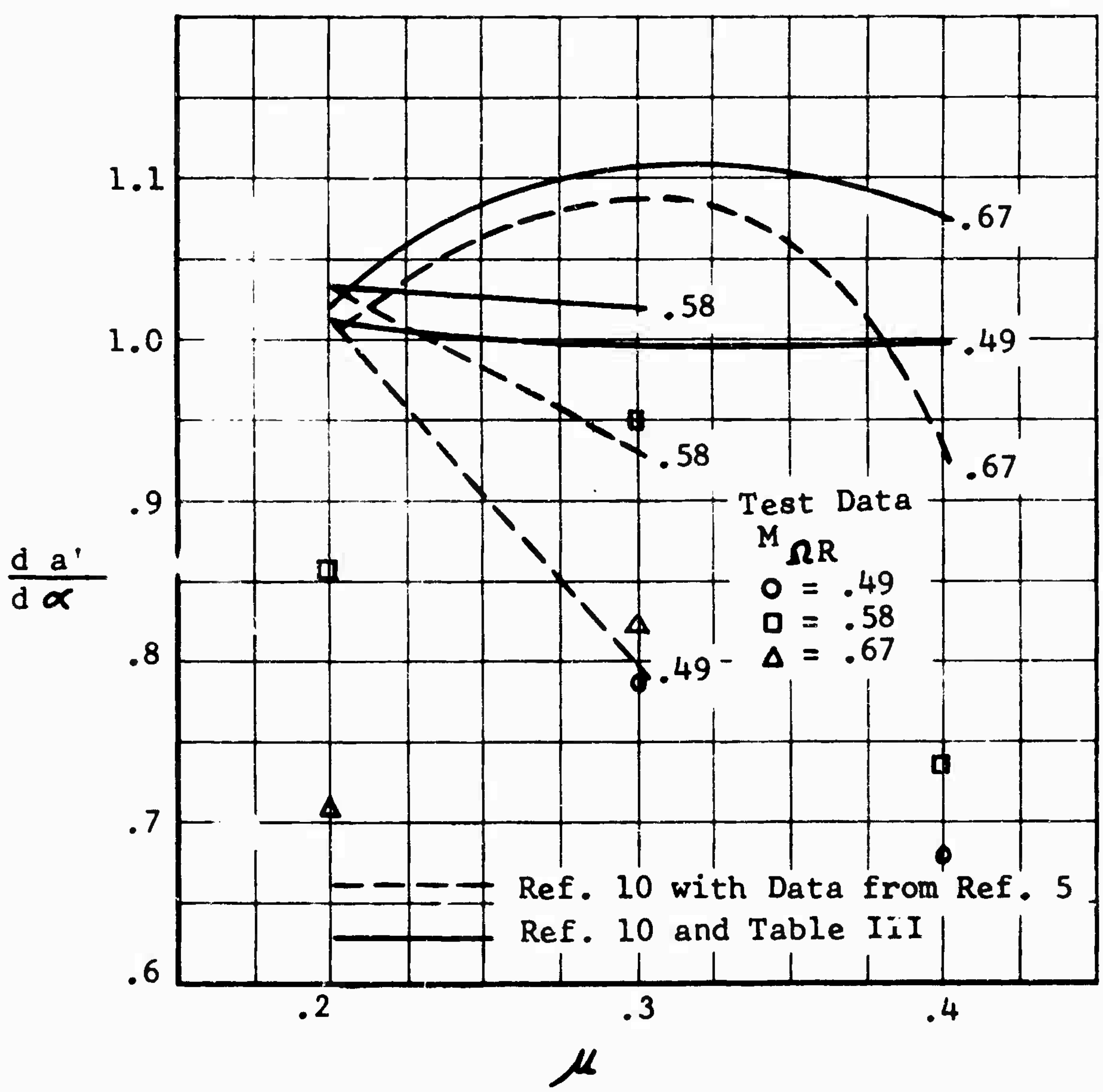

Figure 16. d(a')/dα Variation With Advance Ratio, C_{L_R} = .05.

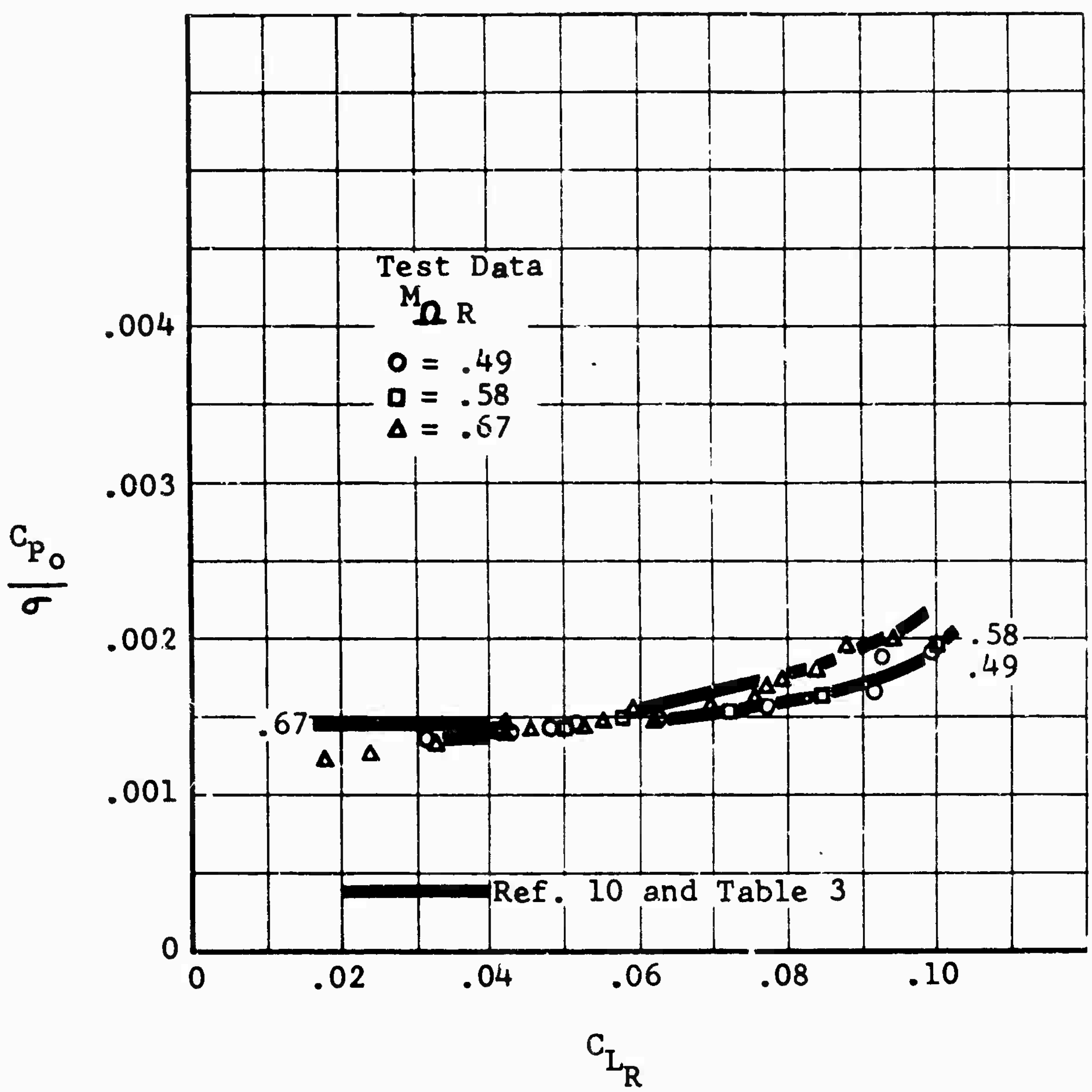

Figure 17. Profile Power Variation With Lift Coefficient, μ = .2, Synthesized Airfoil Data.

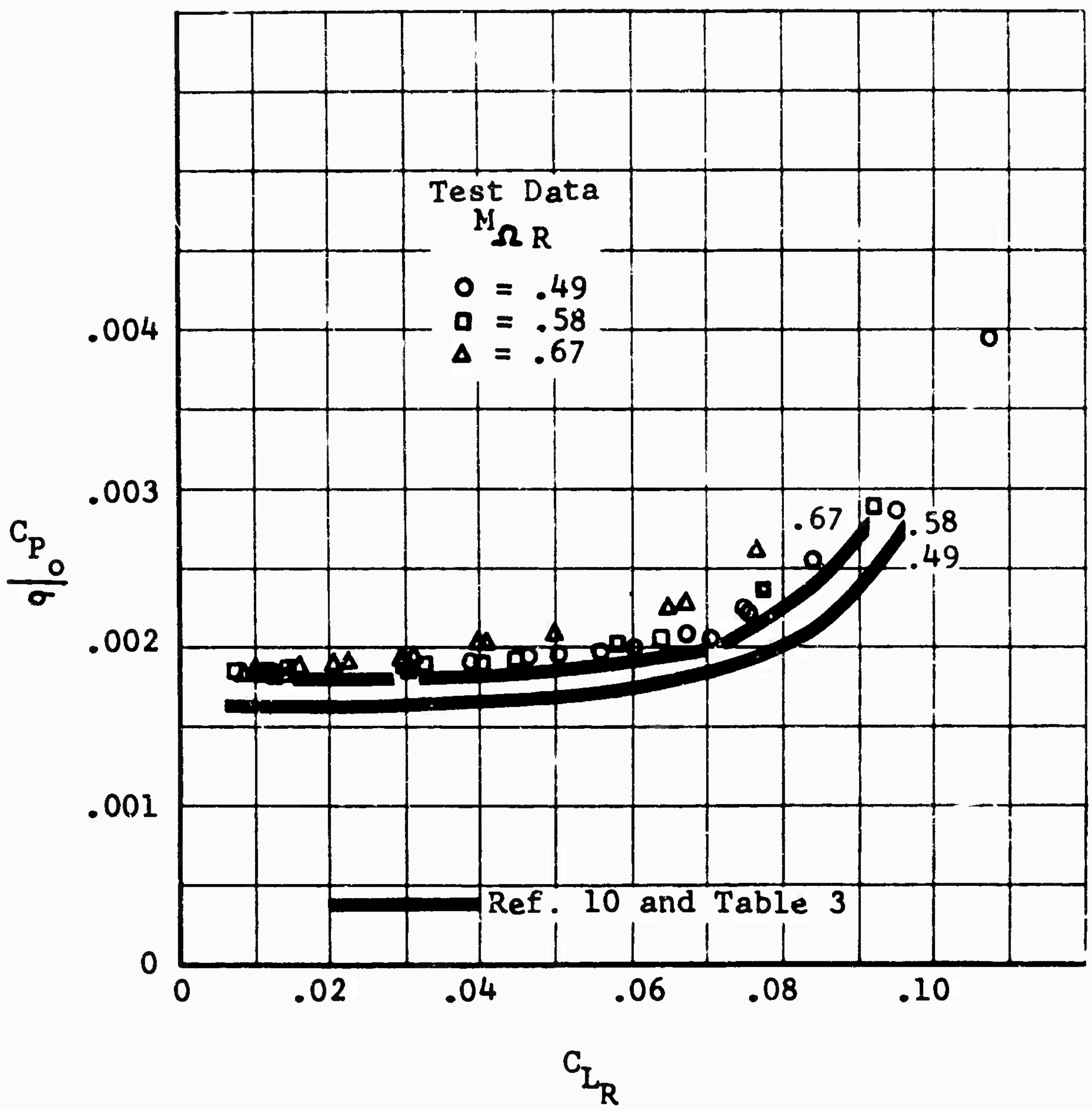

Figure 18. Profile Power Variation With Lift Coefficient, μ = .3, Synthesized Airfoil Data.

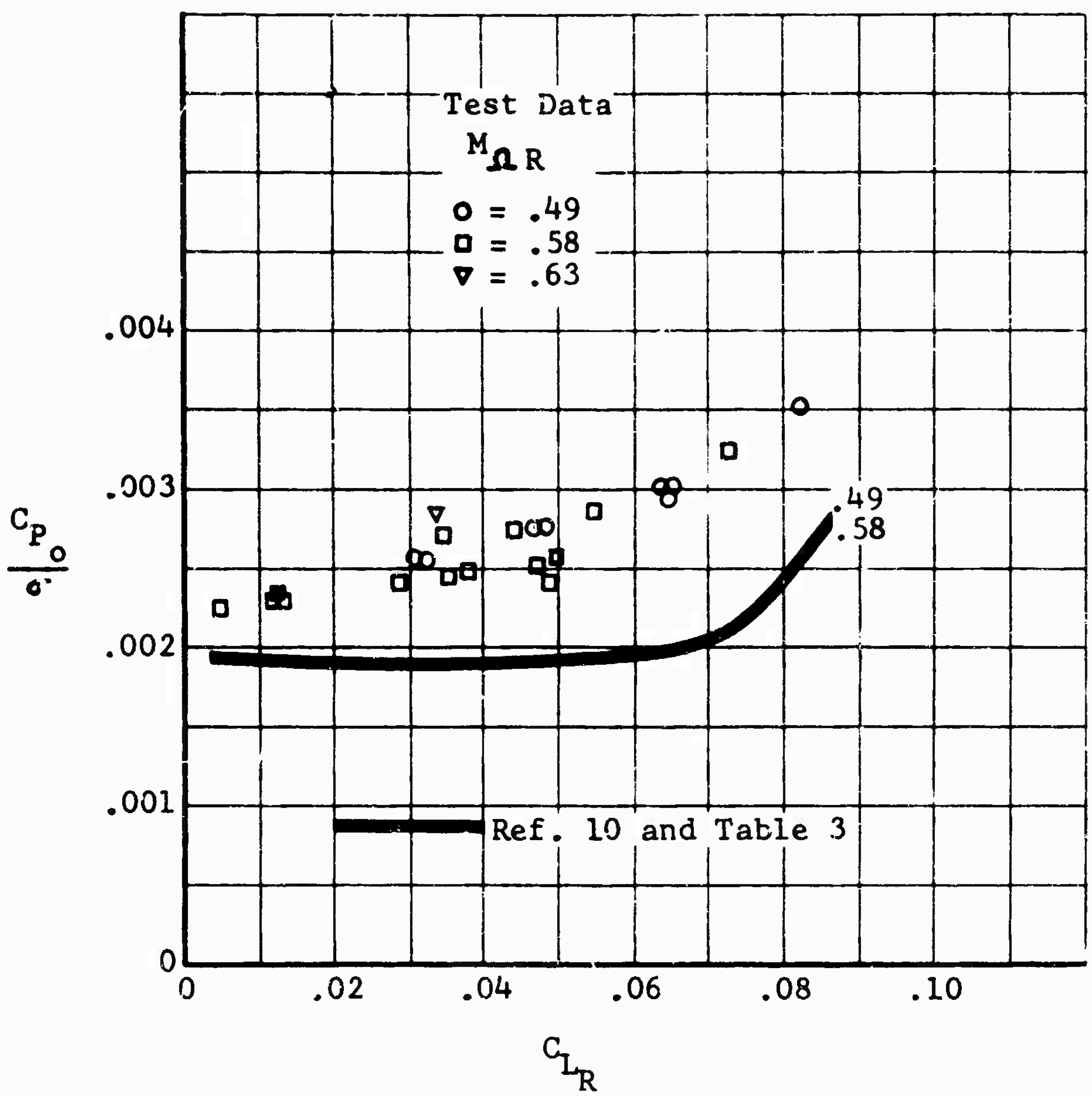

Figure 19. Profile Power Variation With Lift Coefficient, μ = .4, Synthesized Airfoil Data.

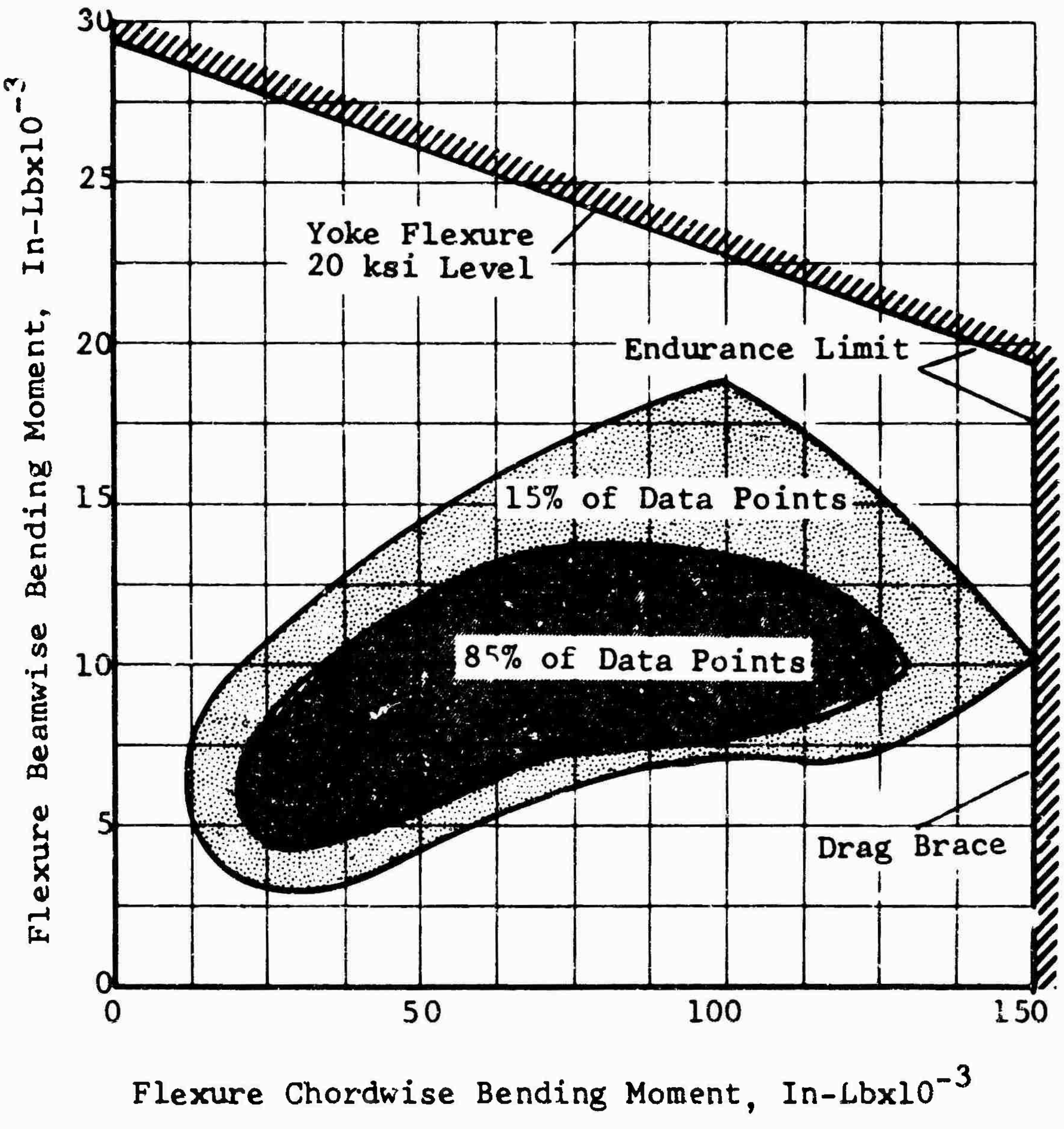

Figure 20. Flexure Beam and Chord Limit Loads.

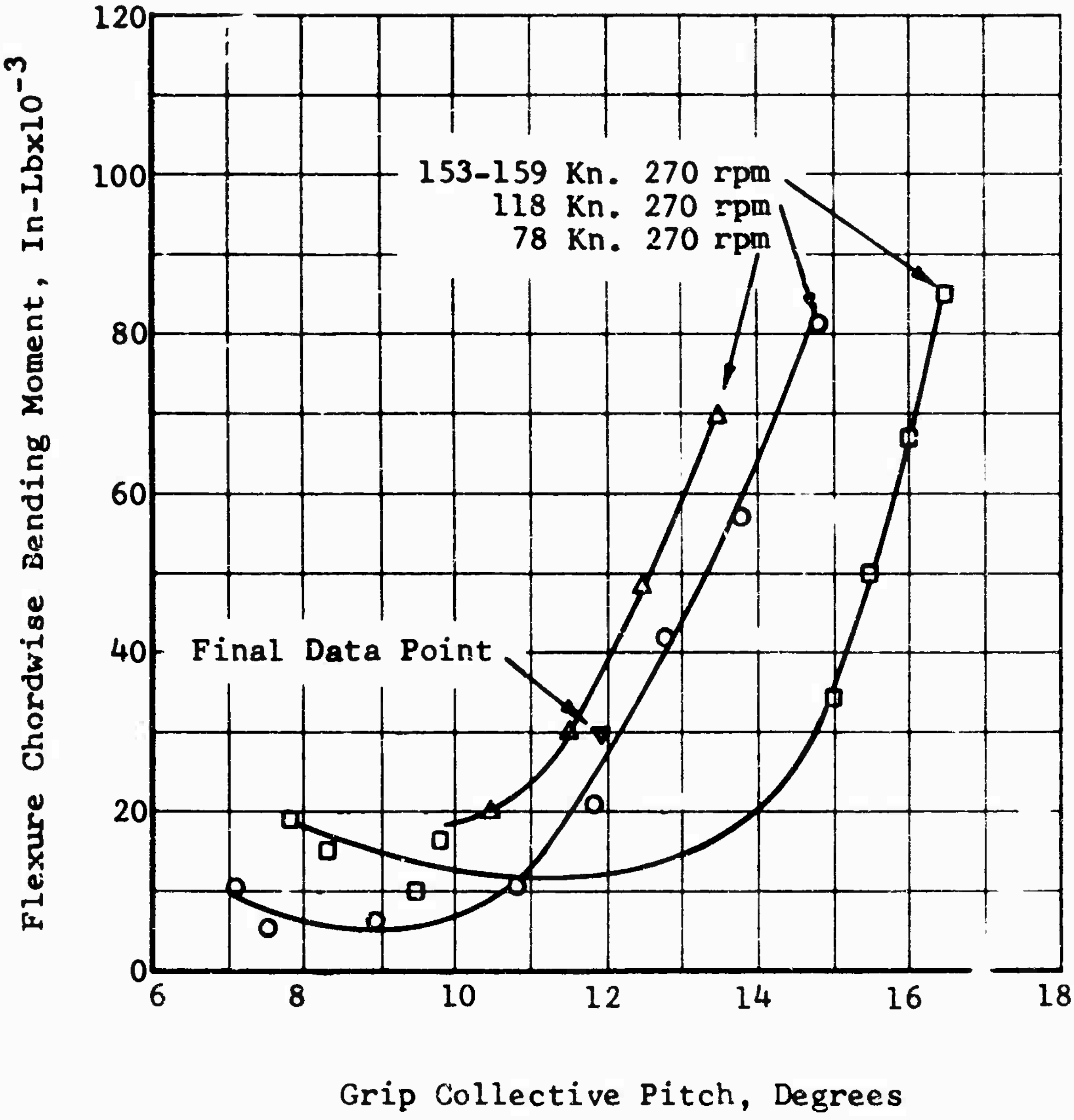

Figure 21. One-per-Rev Flexure Chordwise Load Variation With Collective Pitch.

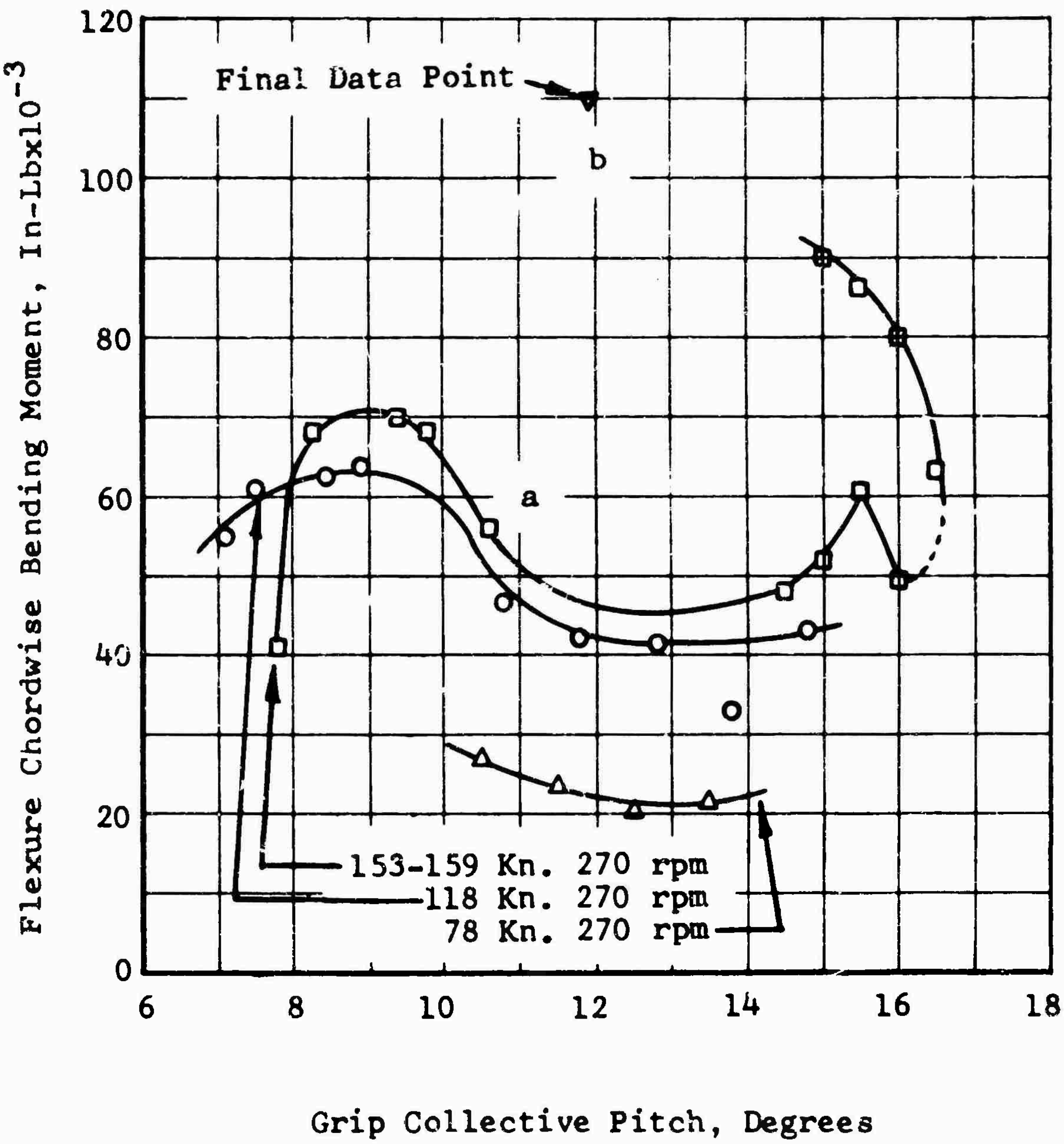

Figure 22. Two-per-Rev Flexure Chordwise Load Variation With Collective Pitch.

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16. Gessow, Alfred, and Meyer, G. C., Jr., Aerodynamics of the Helicopter, Macmillan Company, New York, 1952.

17. Blankenship, B. L., and Harvey, K. W., A Digital Analysis for Helicopter Performance and Rotor Blade Bending Moments, Journal of the American Helicopter Society, October, 1962.

18. Blankenship, B. L., Model 533 Three-Bladed Rotor Wind Tunnel High Speed Test Program, Bell Helicopter Company Memoranda 81:BLB:oah-1489, January 22, 1963.